TORNADO OLMOS COST BENEFIT STUDY

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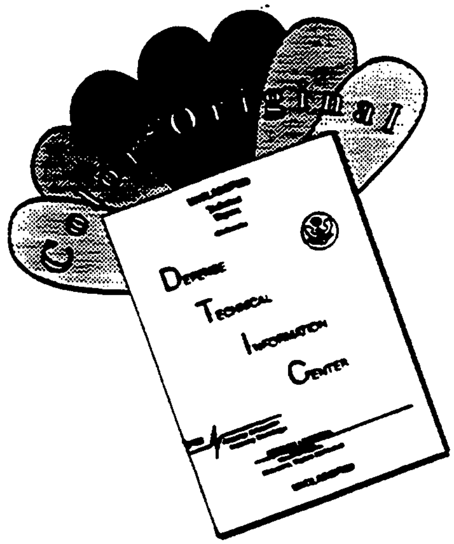

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12.a DISTRIBUTION / AVAILABILITY STATEMENT			*12.b DISTRIBUTION CODE*
13. ABSTRACT (Maximum 200 words) The Monitoring System OLMOS was introduced on the military Weapon System Tornado in order to increase flight safety, system readiness and logistical utilisation. The monitoring of engine performance and inherent life consumption of the airframe and the engine is the prerequisite for a performance and stress oriented on-condition maintenance concept. The study gives a brief system overview and shows the cost benefit trade-off on airframe fatigue, static overload, engine fatigue, and engine operation monitoring. A sensitivity analysis shows the various effects using a primitive counter versus a complex integrated system. Portability of the monitoring system from Tornado to other systems is being considered as well as the expansion potentials.			
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CONTENT

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1. INTRODUCTION

1.1. Identification

This document is the final report on the Tornado OLMOS Cost Benefit Study as performed by Dornier GmbH, a subsidiary company of the Daimler-Benz Aerospace AG, DASA, in response to the contract N68171-95-C-9149 with the European Research Office of The U.S. Army. The Dornier reference number of this report is TN 5043-000000A/01.

1.2. Purpose

The purpose of the Tornado On-Board Life Monitoring System OLMOS is to improve the technical handling of the entire weapon system and to increase flight safety.

The original development goal of the Tornado Aircraft was challenging, some of the requirements were hard to fulfil:

- The in-service time of the weapon system was required to be 4000 flight hours without any scheduled structural modification,
- The maintenance costs should be low, the service factor should be 28 : 1, that means for one flying hour not more than 28 maintenance hours should be required.

On wing level (flight line and shop level maintenance) less personal, compared with former manned aircraft weapon systems, should be able to handle day by day operation.

A high safety standard was required. The manpower cuttings and the long in-service time without major structural modification shall not influence flight safety.

During prototype testing and first in-service trials the flight performance and technical parameters were verified, some aggravating results did require corrective actions.

The dynamic fatigue test, using a synthetic mission profile was showing the first fatigue symptom with less than 1000 flight hours, the main structure did not survive the 2000 flight hours boundary.

The required flight performance could only be reached with high rated engines. The high rating however did increase the fatigue problems of the engine drastically. The TCI (time changed item) interval was shortened, the safe engine life dropped to less than 1000 flight hours.

The maintenance goal was 28 maintenance man-hours per flight hour. The first trial operation was showing more maintenance activities than expected. 70 to 90 direct maintenance hours were required per flight hour.

The expected reduction of maintenance personal did not occur, the technical specialists were collecting up to 90 duty hours a week to repair aircraft and perform inspections.

To keep a high flight safety standard, the inspection interval was kept small, the inspections were planned on a preventive maintenance basis.

The Life monitoring system Tornado was introduced to improve the technical and logistical situation and allow an on-condition maintenance concept.

The study will recapitulate the decision process and outline the expected benefit and expenditures.

1.3. Scope

The Study will reflect the situation during the early flight operation of the Tornado.

The airforce was using the first production aircraft for an intensive in-service trial to gain experience with the system and to detect design shortfalls prior to the conversion of the first operational unit. The detected design shortfalls were evaluated, the results led to the decision to retrofit the aircraft with a monitoring system.

The value analysis presented in this study will recall the decision process and show the various alternatives. In the early days of Tornado operation the financial aspect was less important than the technical feasibility. A risk assessment was smoothening the approach for onboard real time data processing. Trade-off considerations in financial units were postponed. The main reason is that most of the important military attributes can not be weighted in financial terms therefor the comparison of the various alternatives will be mirrored against military objectives. The synthesis allows a comparison of all alternatives, and correlate the system against the aspired dream system.

For better understanding the monitoring principles of

- Airframe fatigue monitoring and evaluation,
- Engine low cycle fatigue monitoring and evaluation
- Engine performance monitoring and trend evaluation
- Static overload and evaluation
- Diagnosis Support .

will be described in detail and financial trade off figures will be added wherever possible.

The study will reflect the technical/ logistical benefits of the OLMOS Monitoring System.

Airframe fatigue:

The main result in this area is the life extension up to 8000 Flight hours. Measuring the actual mission parameters leads to a less stressing mission profile than performed in the fatigue test. The stretching of overhaul inspections and the deletion of many structural modifications is the direct result of the on-condition maintenance system.

Engine fatigue:

The main result in this area is a life extension of the critical engine parts by a factor of 2,5 - 3. The direct measurement of fatigue cycles is leading to a safe and economical engine handling. The savings of TCI parts is in the category of 500 000.- DM per engine over the period of an engine life.

Engine performance:

The monitoring of the engine performance is saving ground runs on the engine which originally were scheduled after 25 flight hours. The performance data are trended on the ground based system, corrective control actions are required on condition. The engine operating time without inspections could be increased by the factor of 3 - 4.

Static overload:

Reports by the air crew on static overloads, like high g manoeuvring or hard landings can be verified by the system, having other parameters available, e.g. actual aircraft weight, wing position and control status, a dedicated inspection can be authorised. General purpose inspections can be prevented in many cases and be replaced by a tailored inspection system. Savings in aircraft downtime and maintenance hours are approximately factor 2 - 3.

Diagnostic Support:

Testability on complex systems is getting more and more important, otherwise too much time and high qualified personal is required for troubleshooting. The Monitoring System provides additional aircraft parameters which can be used to detect failures. Even if the system is not designed to be used as a diagnostic tool, the system provides good support and is helping to improve the maintenance factor.

These above mentioned key issues will be explained in more detail and wherever possible financial figures will be added.

The study is related to the Tornado On-Board Life Monitoring System OLMOS. Therefore the term "Monitoring System", when used as nouns, refers to OLMOS.

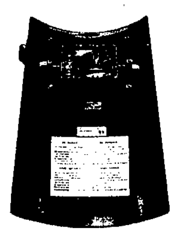
The figure on the following page illustrates the system overview of OLMOS.

OLMOS

ONBOARD LIFE MONITORING SYSTEM

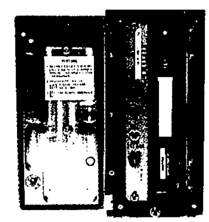
FOR GERMAN AIRFORCE TORNADO

Recorder-Beacon-Airfoil with Crash-Recorder RBA + CR

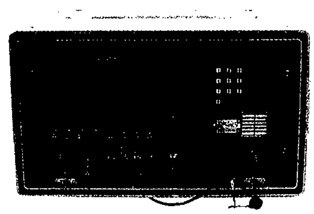


Data-Acquisition-Unit DAU

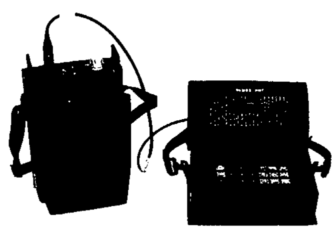
Maintenance-Recorder MR



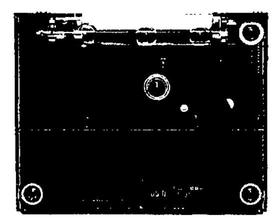
Recorder-Test-Unit RTU



Hand-Held-Terminal with Battery-Package HHT + BP



MR-Tape-Cassette

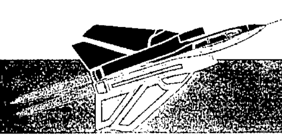


OLMOS-Ground-Station OGS

System Overview. The Onboard Life Monitoring System (OLMOS) of Tornado gathers and processes onboard stress relevant data to determine life cycles of the engines and structure. It monitors limit exceedance and events and stores the results onboard in non volatile stores. The onboard functions have been implemented into the Data Acquisition Unit (DAU) of the existing Crash Recorder System (CR). The Maintenance-Recorder (MR) stores flight data onboard of several flights for further maintenance purposes.

Configuration-Control and Logistic-Management: BMS **TA4, TA5 and TA6**

The logistic and technical evaluation of the data are implemented into the OLMOS Ground Station (OGS) that has a data link to the central logistic system (BMS) of the German Airforce (G.A.F.). By means of a Hand Held Terminal (HHT) the onboard collected data are displayed and transfered to the OGS. The Crash Recorder Data are transfered by the Recorder Test Unit (RTU) to the OGS for display and data evaluation. The Maintenance-Recorder (MR) data are evaluated at the OGS as well.



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2. ON-BOARD LIFE MONITORING SYSTEM OVERVIEW

2.1. System Origins

2.1.1. Accident Investigation

In the early 1960s the German Air Force fighter bomber inventory was renewed, the Lockheed F-104 Starfighter jet aircraft was introduced into service. The increase in performance and technical complexity was considerable and the Air Force had to overcome many problems. The system was showing a high failure rate, fatal technical errors and many pilot errors were leading to many aircraft and crew losses. To increase technical reliability and operational confidence within the system the discipline of accident investigation became very important. A recording system was developed and part of the F-104 fleet were retrofitted with an accident and maintenance recorder to allow technical investigation in great detail. The high quality of the gained data led to standard diagnostic procedures during normal flight operation and to special investigation programs with the aim to improve the technical standard of the weapon system. The technical changes to the entire F-104 fleet were significant, the accident rate dropped drastically and the technical crash investigation became a routine and standard procedure within the airforce. The F-104 crash recorder system with a deployable airfoil was declared as an essential equipment for fighter airplanes within the German Airforce. The Tornado aircraft as the successor of the F-104 was equipped with a deployable recorder.

2.1.2. Fatigue Monitoring

The F-104 Starfighter was designed as a fighter aircraft, however the tactical role changed to fighter bomber and long range interdiction fighter bomber. The total cross weight of the plane was increased and the fragile airframe was operated at the edge of the authorised load envelope. Special weapon delivery manoeuvres were over stressing the fuselage and quite often static overloads were detected. After some total losses due to fatigue and static overloads it was decided to monitor the fatigue situation closer. Accelerometers (g-meter in z-direction) were installed in the entire fleet, and the company IABG was requested to monitor every airframe on the bases of the reported "g-counts". This method was not very accurate , because of the missing "actual weight", but overall the life monitoring program of the F-104 fleet was very successful and the Air Force had good visibility of the inherent life situation of the entire fleet. The Tornado should be equipped with a "N_Z - G Counter", to have visibility of the fatigue situation starting with number 1 production aircraft.

2.2. Objectives and Technical Approach

The requirements for the Tornado Life Monitoring System were influenced by three major objectives:

- Life extension of airframe and engine
- Monitoring and evaluation of events, performance trends and incidents
- Improvement of flight safety, operational readiness and maintenance efficiency.

2.2.1. Overall Requirements

The overall OLMOS requirements did read as follows:

Life Extension:

The inherent life of the airframe can not be measured. The reference life is the airframe tested in the dynamic fatigue test. The requirement for the Monitoring System shall correlate the mission parameters of the operational aircraft and the parameters from the fatigue test.

The same philosophy applies to the engine. During engine testing the critical engine parts (group A parts) are subject of a fatigue test. The same reference mission profile used for the airframe is used for the engine. The same basic requirement applies to the monitoring system. The system shall correlate the mission parameters of the operational aircraft and the parameters from the fatigue test.

Event Monitoring:

In classical flight operation events like over-G or hard landings are reported by the crew. The verbally given information is often subject of "guessing and assuming". The monitor shall watch the flight parameters and indicate events. Important secondary parameters shall be recorded prior and after the event. Inspections should be tailored to the event.

Flight Safety:

The Monitoring System shall operates automatically, the crew shall not be distracted by additional cockpit information. Flight safety shall be increased by using the collected information for additional training and crew briefings.

Operational Readiness:

The monitoring system shall not influence the operational turn around or the availability of the aircraft. The data collection on aircraft shall take place without powering the aircraft, data evaluation shall be possible on aircraft for fast go-nogo decisions. Aircraft on outbound missions should not require maintenance activities to obtain the data for the logistic system. Accounts shall be obtained on board, self-contained operation shall be possible for at least 5 missions. The diagnostic support should speed up trouble shooting, engine trend data should be used to ensure optimum engine operation.

Maintenance Efficiency:

The monitoring system shall improve the efficiency of the maintenance activities. The effort for data collection and evaluation shall not consume all of the savings of the on-condition maintenance. There shall be a benefit for the operational unit, not just for the depot level maintenance. After the introduction of the system the overall maintenance factor shall drop.

2.2.2. Technical Approach

The functional requirements are dictating the technical approach. One single company is hardly in a position to fulfil all requirements, the on-board monitoring is partitioned into the following functions:

Data Acquisition

Data Acquisition is done by the already incorporated crash recorder system. The sampling rate of some dedicated parameters are increased, to allow proper data processing. A few parameters are added to increase monitoring accuracy.

Data Processing

On-board dedicated software packages will run on dedicated processors.

CPU 1 handles the data input, and organises the data output for the tape recorders and the dedicated on-line programs. Beside these overall tasks the CPU 1 calculates the structure life and Event Monitor.

CPU 2 and 3 are handling the engine life program (left and right engine) and engine performance trending. The life accounts will be transferred to CPU 1 for storing.

The Hand-Held Terminal, HHT, will function as a data retrieval unit, quick look diagnostic tool and data transfer device to the ground station. The HHT is a Aerospace Ground Equipment and will cope with AGE environmental requirements.

The OLMOS Ground Station, OGS, provides all necessary ground functions for evaluation and sorting. Back up functions to compensate on-board failures are available at the OGS. The OGS is a commercial personal computer and is used in a shop level environment. No militarised requirements applies to the OGS Hardware.

Data Assignment

The collected data are assigned to the dedicated structure (airframe) and engine. The material inherent life is a special datum and needs special logistic assignment. CPU 1, OGS and the logistic host computer require a dedicated data handling and depend on a overall logistic configuration control.

Logistical Administration

The centralised logistic management request the lead function in logistic management configuration control. Steering parameters to provide proper on-board processing will be provided by the central system to the OGS. The life accounts will be managed by the central system. The structure data will be forwarded to IABG for further evaluation. The engine accounts are accessible in the operational unit.

2.3. Technical Implementation

The design and implementation of the system was influenced by the technical baseline of the Tornado aircraft. Existing systems where to be used to a maximum extend, data acquisition was to be provided by the already implemented crash recorder system. New cables where only allowed were absolutely inevitable.

2.3.1. Design Principles and Constraints

The best introduction for OLMOS was to implement it by retrofit, i.e. to modify the existing hardware and software of the Crash Recorder System and to utilise signals and parameters from the aircraft already provided. At the same time power consumption, mass and space envelopes where not to exceed.

The aircraft operation imposed additional constraints. For instance, there should be no requirement for additional manpower and no additional interactions between crew and systems. Although unavoidable modes of operation required some recovery techniques, like to store data on power-down when the engines are turned off and to process them during the subsequent cycle of operation. During ground operation the OLMOS system was to be able to operate self-contained, that means without the need of being powered by aircraft generators, or external power, provided by the base infrastructure.

Finally, OLMOS happened to be a system of living requirements, being used to implement the concepts of on-condition maintenance step by step, where lessons learned and technical opportunities continuously influenced the design.

2.3.2. On-Board Processing and Accounting

The on-board equipment contributing to the On-board Life Monitoring Systems are the Data Acquisition Unit (DAU) and the Crash Recorder System (CR).

The DAU acquires data directly from A/C sensors and via a data bus system from other LRU´s. It calculates engine low cycle fatigue (LCF) load as well as structure load values in real time and accumulates these. It does the event monitoring to observe static overloads and acquire performance trending data. It distributes parameters to CR and MR. The CR and MR are data storing facilities for incident and other technical investigations. On the MR tape unit more data can be stored over a longer period than on CR.

The DAU was tasked to monitor the engine and the structure as well as to store relevant parameters as triggered by events, without any impact to the original functions. The retrofit of the DAU included the transformation of the technology of the original hardware into new one to gain space for additional functions. An additional processor was introduced to cope with the amounts of data that where now to be processed on-board and on-line by the DAU.

2.3.3. On A/C Evaluation

Failures logged within OLMOS and the occurrence of events will trigger a failure flag at the Central Maintenance Panel (CMP). Further investigations requires the Hand-Held-Terminal (HHT).

The HHT serves as data carrier between the DAU installed in the A/C and the OLMOS Ground Station (OGS). The HHT enables a short diagnosis directly on-A/C, during which both, the HHT and the DAU are powered by a portable battery package. The major advantage of this on A/C evaluation is the possibility to categorise events immediately and to decide on any actions required.

The Recorder Test Unit RTU is a facility to test the DAU sensor signals and the CR system. It is also used as data storage for the CR data. The CR data can be displayed in the RTU, and loaded from the RTU into the ground station.

2.3.4. On Ground Evaluation (shop level)

The OLMOS Ground Station (OGS) is a standard PC system. It is used to display and process all data imported from the flight line. It provides the necessary support

to the maintenance personal to evaluate events, other maintenance data, trend data and life counts. Back up routines are available to edit life accounts, if the on A/C system indicates malfunctions. Configuration control on all monitored subsystems is handled by the OGS. The station is the front end for the central logistic support system. Life records are sent to the Logistic Information System on a day by day basis to support planning and control activities on higher command levels.

2.3.5. Centralised logistic fleet management

The overall logistic fleet management is performed by Logistic Command and Material Command. Configuration Data, Life Records, Depot Inspections and Aircraft assignment is a centralised function. The information gained through the OLMOS is a major data input to the Tornado management. Technical and logistical status reports are updated within 24 hours throughout the entire fleet.

2.4. OLMOS Operation

The operation of the Tornado Monitoring System is quite complex. User of OLMOS functions are:

- On aircraft maintenance (Flight Control mechanics).
- Shop level maintenance (Flight Control mechanics, engine mechanics and technical supervising personal)
- Technical Group (life records, maintenance planning)
- Logistic Support Command (life records, Depot overhaul planning)
- Industry (national Tornado Industry: DASA, IABG, MTU)

Operational Unit Operation:

The System has to be handled by the operational unit. The mechanical shop, the system is assigned to is "Aircraft Control Systems". The mechanics of this shop are working "On Aircraft" and "Off Aircraft". The shop is responsible for data handling and evaluation, as well as maintaining the entire Monitoring System. The routine operation on the main operating base is the following:

Data collection:

After last flight every day the on-board data accounts will be dumped via a Handhold Terminal (HHT) to the shop level workstation (OGS). The dumping does not require

aircraft power, and needs about 1 minute per aircraft. Beside the routine data dump once a day data will be collected on dedicated aircraft, if events are reported or indicated by the system. In these cases a quick look at the HHT is possible to enable a go-nogo decision.

Data Evaluation:

The content of the HHT will be transferred to the workstation in the shop. The routine evaluation will cover engine fatigue, engine trending and airframe fatigue data. The data will be sorted and filed. Trend data will be evaluated to filter out engines for ground service and maintenance.

Data resulting from events or air crew reports will be evaluated to define inspections or other maintenance actions. Those data used for trouble shooting will be recorded in the maintenance records.

Data Transfer:

Data with life information will be transferred to the Logistic System for filing and evaluation purpose.

Command level:

The Fleet management will be performed by the Logistic Command and the Air Material Command. The individual life records are the basis for all life related modifications and for depot planning.

Industry level:

The industry involved in fatigue testing for the structure and the engines may receive special data for pre evaluations, or for investigations. For special fatigue investigations additional data may be provided from earmarked aircraft. Those data are strain gauge data and will be sent direct to industry by the operational unit.

3. VALUE ANALYSIS

3.1. Methodology

Analysing the situation in the early days of Tornado operation and choosing a proper method for a "Trade off Study" two aspects were realised. Even with well defined and documented maintenance echelons, monetary data on wing level (shop level maintenance and on aircraft service) are not available. Higher echelon levels (depot and industry repair) however are providing monetary data. The "Value Analysis" was chosen because this type of study allows the usage of self defined values and monetary units as well.

3.2. Objectives

The Objectives are organised in three levels, only the detailed levels will be shown in the preceding tables. The hierarchy is:

3.2.1. Main Objective

The main objective to be reached is a reliable and accurate monitoring of the inherent life of the weapon system and the monitoring of the operational performance.

3.2.2. Sub Objectives

Sub Objectives can be obtained when breaking these very general objectives down in more precise terms.

- Increase of inspection intervals, increase of usage time
- Monitoring of events and incidents
- Increase of availability, safety and effectiveness

3.2.3. Single Objectives

The Single Objectives that will be analysed in more details are:

- Increase of the Depot Inspection Intervals (DI)
- Stress-oriented part change for structure
- Stress-oriented part change for engine
- Monitoring of static overloads (mainframe)
- Monitoring of static overloads (A/C controls, e.g. flaps, slats and stores)

- Recording of all significant Aircraft parameters for evaluation of incidents
- Efficient and flexible Operation
- Improvements of Aircraft diagnostic and maintenance
- Allowing user-friendly handling of the entire system
- Secure and reliable data handling

3.3. Definitions

The following definitions are tailored to this study, they may not be used in official publications.

3.3.1. Structure dynamic test

The major fatigue test of the PA 200 airplane (Tornado) was carried out with all critical structural parts of the centre fuselage. The variable wing was incorporated in this test, to get best visibility of the actual load situation. This dynamic fatigue test of the major parts is called major aircraft fatigue test (MAFT). The load scenario was based on a synthetic flight profile, gained by an industrial analysis of a typical fighter bomber mission.

The result of the MAFT was leading to flight limitations, inspection intervals and modification requirements. The limitation factors were part of the service release document.

3.3.2. Engine dynamic fatigue test

A dynamic low cycle fatigue test was performed as part of the development program RB 199 engine by Turbo Union. All critical engine modules (group A parts) were stressed mechanically and thermally in a centrifuge to establish the operation limitation measured in cycles. The critical engine modules are flight safety critical, because bursts of these parts may cause aircraft losses. The various introduced loads can not be combined mathematically, it is necessary to examine the damage at a dedicated area. The term "reference cycle" is used to describe a standardised load collective.

The engine fatigue test was leading to life limitation of the various engine modules, to control engine life time in flight hours, a special constant (beta factor) was introduced. (Flight hour x Beta = Cycle). Because of the individual authorised cycle life on module or part level, every module got a different flight hour limitation. The basis for all beta factors was a synthetic flight profile, similar to the profile used in the MAFT.

The cycle limitation of the group A parts were part of the service release document.

3.3.3. Material Deterioration

Material in use will be subject to wear. All parts of the aircraft may alter, however flight safety criteria and directed in-service time require maintenance activities throughout the total usage time.

The main categories of cumulative wear in metal structures are:

Fatigue

Any change in load will cause fatigue, low cycle fatigue and thermal fatigue are the main fatigue categories used in the Tornado monitoring system

Wear

Friction between metal surfaces cause wear. Present monitoring systems will not be able to monitor wear with the exception of metal chip detection in oil systems of engines. In general, wear will be detected during depot overhaul by visual inspections.

Corrosion

Oxidation of metal surfaces, favoured by salt spray or other aggressive atmosphere is called corrosion. Monitoring Systems can not allocate areas of corrosions. In general, corrosion will be detected during depot overhaul by visual inspections.

Wear that is of non cumulating nature, is called:

Static Overload

Values for static overload are experimentally gained during the airframe test phase. Monitoring Systems are able to control static overloads, using mission parameters

3.3.4. Preventive Maintenance

Based on the service release document inspections are ordered in terms of flight hours. This method is dictated by flight safety criteria, however uneconomical. For wear and corrosion preventive maintenance is ingenious, to cover fatigue problems preventive maintenance is senseless.

3.3.5. On-Condition Maintenance

Fatigue and static overloads requires a monitoring system to utilise the inherent life of the airframe. This method is economical, saves maintenance resources and still stays with the rules of flight safety.

3.4. Characteristics

3.4.1. Lengthening of Inspection interval

As a result from the major airframe fatigue test the structure was released to service with precise conditions. The mainframe was released to service for 2000 flight hours. In addition an inspection chain was established, starting in the operational unit and ending in the depot overhaul inspection. During these inspections fatigue related investigations (e.g. cracks) are of vital importance. Knowing the real load situation in comparison to the synthetic profile used during the fatigue test, may cause a lengthening of the inspection intervals.

Criteria: reasonable effort to measure the cumulative loads (fatigue), correlation with MAFT.

3.4.2. Load oriented Part change

The release of the structure was combined with "time changed item" (TCI) - modifications. These modifications were quite expensive, so it was the intention to lengthen also the TCI time of the critical structure parts. The TCI intervals and the depot inspection intervals need to be correlated.

Criteria: reasonable effort to measure the cumulative loads (fatigue), correlation with tested structure Lifetime

3.4.3. Load oriented Part change for engine

The engine parts were tested in "cycles" and the service release was also given in cycles. The transformation into flight hours takes place via the "beta factor".

Two levels of load adaptations are possible,

- the statistical method to adapt the real mission mix to the synthetic mix. This method is just updating the "beta factor" of the individual module, safety margin is still required to cover all variations of missions.
- direct measuring of cycles, calculating of fatigue accounts in cycles and controlling the critical engine parts on an individual basis. Additional safety margins are not required.

Criteria: reasonable effort to measure the cumulative loads (fatigue), correlation with tested engine Lifetime

3.4.4. Static Overload on Airframe Structure and Engine

Static Overloads caused by symmetrical and asymmetrical exceeding of acceleration forces. In normal flight operation generally exceeding happen in "Z" direction, asymmetrical acceleration forces do have additional vectors in "Y" or "X" direction. The Tornado structure is certified for 5 g acceleration force in Z. Asymmetrical loads are certified up to 3,5 g.

Beside the main forces resulting from aircraft manoeuvring additional events may happen, stressing the main structure or attached parts. These events are e.g. hard landings and engine compressor stalls (surge). Static overloads have to be reported by the crew, the objective of the monitoring system is to get independent data on the event (endurance, actual weight, peak force), to enable the mechanics to perform an event tailored inspection. The trigger condition is keyed to the service release limitations, not to the flight handbook.

Criteria: reasonable effort to detect events and record associated parameters.

3.4.5. Static Overload on Aircraft Controls and External Loads

Beside the main structure restrictions the service release certificate identifies speed limitations to control areas and external stores. These limitations are depending to wing sweep angle and other parameters. The crew reports in this area were almost non existent. Due to the flight safety aspects the monitoring system records all relevant parameters and allows the maintenance personal special inspections and repair.

Criteria: reasonable effort to detect events related to stores and control panels and record associated parameters.

3.4.6. Parametric Recording

Acquisition and recording of flight parameters, gained directly or calculated from directly gained parameters. The parameters can be recorded on various devices (e.g. solid state, magnetic tape) and may have a high survivability rate (crash recorder).
For accident or incident investigation or technical investigation the following factors are important:

- amount of signals

- accuracy of signal
- recording frequency of signal
- recording time
- crash survivability

Criteria: reasonable effort to record aircraft parameters and store them on recording devices.

3.4.7. Flexible and efficient field operation

Monitoring systems shall not influence field operation. The main areas of concern are:

Operational Turn around

The operational turn around has to be free from data dumping and lengthily data evaluation. A fast decision is required to clear the aircraft for the next mission. An "on aircraft quicklook" facility must be available.

Flexible Data retrieval

The data retrieval, collecting and transfer shall be possible under all conditions, like cross country missions, out of area missions, peace time and wartime operation.

Data accuracy

The gained data shall be readable, the failure rate shall be as low as possible.

Mission Influence

The monitoring system shall perform without air crew interactions. The efficiency of missions shall increase.

Ground System efficiency

Provisions for further data transfer into the ADP infrastructure of the operational unit.

Criteria: reasonable effort to provide operational flexibility and allow efficient field operation.

3.4.8. Optimisation of Diagnosis and Troubleshooting

The existing test concept Tornado is based on an already existing system, the OCAMS (On-board Checkout and Maintenance System). The Monitoring System shall supplement the existing system, providing additional information for

troubleshooting. Basically the system is in a position to compare any deviation from normal operation. For a high confidence factor, the method of trending is the most appropriate one.

Criteria: reasonable effort to provide additional diagnostic information.

3.4.9. User-friendly Handling

The Handling has to be tailored to the qualification level of the maintenance personal. In the operational unit the system is used by mechanical specialists. A system designed for the qualification level of flight test engineers is not appropriate. The user interface shall allow fail safe data handling and appropriate configuration control.

Criteria: reasonable effort to provide a user-friendly software interface to allow safe handling in the operational unit.

3.4.10. Data security

The gained data are living data and may influence flight safety. The handling concept shall allow maximum data security.

Criteria: reasonable effort to provide safety features for data handling to satisfy ML and Log Command requirements.

3.5. Alternatives

To get better visibility, all possible alternatives of a Tornado Monitoring System are listed and described below. The baseline configuration of "Number One Production Aircraft" is the reference alternative to start with. The present Flight Data Recorder (FDR) programme is considered as the high end configuration of OLMOS and will be the realistic top alternative.

3.5.1. Tornado with Crash Recorder (Baseline programme)

Analogue data, digital data, frequencies and discrete data are acquired by the Data acquisition Unit and converted into digital data. The data are sorted and recorded on the endless crash recorder. In addition the cockpit voice is recorded on the tape.

3.5.2. Tornado Baseline + G Meter

In addition to the baseline functions an accelerometer measuring the acceleration in the pitch axle is installed. The accelerometer is accounting load collectives in pitch

direction and is storing this information cumulatively. The read out is visually. The reading is transferred to a formula and sent to the IABG (German firm).

3.5.3. Tornado Baseline, G Meter and Fleet Leader Maintenance Recorder

In addition to the baseline functions and the G - meter for some selected aircraft a mass data recorder is installed. This maintenance recorder is recording all available aircraft parameters for several hours of flight. On top of technical investigations, mission profiles and load profiles can be verified, using means of statistical methods. Strain gages can be located on critical airframe structure parts and the results can be evaluated by industry.

3.5.4. Tornado Baseline and 100% Maintenance Recorder.

A maintenance recorder is installed in all Tornado's. Life calculation is possible on all aircraft. The data evaluation takes place on ground. Static overload and diagnosis requires data retrieval and evaluation after every flight. The system is limited to routine operation on the main operating base. Life calculation on a main frame computer provides maximum accuracy.

3.5.5. Tornado Baseline OLMOS and Fleet Leader Maintenance Recorder

The On-board Monitoring System is processing load information on-board and records life counts for the structure and the engine. Static overload events and the engine performance are monitored. A fleet leader maintenance recorder is installed in some of the aircraft for the purpose of technical investigation programs and software verification.

3.5.6. Tornado Baseline OLMOS maturing and Flight Data Recorder

The digital flight data recorder is replacing the endless crash tape recorder and the maintenance recorder. All aircraft parameters are available and easy to retrieve for crash or technical investigation. Static overload events or diagnostic investigation can depend on best available information, easy to obtain and evaluate.

3.6. Evaluation

The characteristics of all given single objectives are correlated with the various technical solutions (alternatives). In the matrices (figure 1) the individual characteristics are allocated to the required single objectives. The scaling is standardised to "10". The lowest value "0" indicates a non-fulfilment of the requirement or objective, a "10" indicates compliance. All figures were the result of intensive discussions with specialists and the evaluation of the in-service trials. The alternatives introduced as possible solutions were based on assumptions and

theoretical modelling. In the proceeding figure (figure 2) the results were combined with a weight factor, the factor reflects the overall priorities of the German Airforce.

3.7. Value Synthesis

The value synthesis used is the combination of the weighted factors by means of addition. There is another possibility using a multiplication combinations that means very low rated characteristics have a great influence degrading the overall rating. For the purpose of this study the addition method is good enough separating the various alternatives.

4. AIRFRAME FATIGUE

Material deterioration is a broad field and only the category of fatigue deterioration is subject of on-board monitoring. Other than fatigue deterioration will not be discussed because no monitoring tools are available to observe and record corrosion or other categories of wear.

4.1. Basics

Structures for aircraft, constructed by conventional methods are composed of light metal alloys, like aluminium. Main structure parts may contain special material to handle either high temperatures (aft section areas) or high load forces (e.g. wing / fuselage connection). The structure parts are mainly assembled with rivets. Material Fatigue can not be measured without destroying the material. Fatigue problems therefore can be detected only by visual inspections. The prerequisite however is a complete disassembled structure. Mechanic specialists inspect the condition of the structure visually; looking for fractures, loosened rivets and areas of corrosion. To ensure a high safety standard these inspections are scheduled regularly as a preventive maintenance activity.

4.2. Fatigue Test

To prove the mechanical design of the structure a fatigue test for the major parts of the central fuselage is performed. This test is called major airframe fatigue test. This test is using a synthetic, well defined flight profile and leads to the following results (samples):

	Area	limitation	prop. Mod
1.)	Centre main frame centre	2000 h	
2.)	Shoulder frame Assembly	300 h	10640
3.)	frame 9110 connecting flange	800 h	10891
4.)	frame 9110 splice	800 h	11103
5.)	frame 110545	500 h	11023
6.)	frame 800	500 h	11025
7.)	wing torsion box (lower plank)	1200 h	20128
8.)	I/B Pylon upper plank	1330 h	20095

The critical result of this fatigue test is the 2000 h limitation on the centre fuselage. This value has to be interpreted as the economical usage limit of the aircraft. On top of this the test indicates usage limitations of structure areas prior to 2000 flight

hours that require structural modifications. The overall strategy for the monitoring system is to compare the synthetic load collective used in the fatigue test with actual load collectives gained from operation. The fatigue test during the development phase of the weapon system is under close observation of the government authorities (ML, equivalent to FAA). Using this test as the reference test guarantees the approval of the results. The monitoring system is not measuring the fatigue, but records the load collective of every individual flight. The deterioration of the aircraft structure is calculated on ground (industry level) comparing the collected load collectives with the synthetic loads of the fatigue test.

4.3. Expenditures for Production Aircraft

To gain a complete picture for the expenditures of the production aircraft is very difficult. Development costs, costs for the intensive test phase, production costs and retrofit costs are involved. It was decided not to include these basic costs in the expenditure table below. Expenditures therefore will be defined as those costs that has to be added on top of the basic costs at the decision point. The following table gives an overview of expenditures categories.

1.) A/C Modifications (cabling) to enable the embodiment of the maintenance recorder; new sensors including connecting cables
2.) Embodiment of maintenance recorders testing, flight trials
3.) Modification of DAU, HW update and SW development (Dornier, IABG, MTU and MBB)
4.) Development of new Ground Equipment (HHT, RTU, OGS)
5.) Procedure Changes and Adaptation in the central Logistic System
6.) Procedure Changes Flight Line Organisation, Retraining

For the airframe fatigue monitoring an estimated portion of the total development and retrofit costs applies.

1.) MR Wiring	Mod 480 B	cost
2.) MR Provisions	Mod 10825 A	cost
3.) Lateral Accelerometer	Mod 10928 A	cost
4.) Strain Gauge Provisions	Mod 10990 A	cost
5.) MR Procurement	Mod 11052A	cost
6.) DAU Update (% for frame)		cost
7.) IABG DAU SW (W^*N_Z)		cost
8.) AGE (OGS, HHT, RTU) (% for frame)		cost
9.) Accelerometer Deletion		saving
		Total expenditures 12,3 Mio DM

The table does not provide any detailed figures due to classification restrictions. The overall figure should be considered as a rough estimate only.

4.4. Benefit

The Benefit changing from preventive inspections to on-condition inspections is considerable. Knowing the real load collectives of the aircraft the originally authorised flight hours can be lengthened by a factor of 4 without the loss of flight safety. The required structural modifications listed below are giving a overview of the savings:

	Mod #	auth. Hours	actions	auth. Hours
1.)	20128	1200 h	min. Mod	4000 h
2.)	20095	1330 h	min. Mod	4000 h
3.)	20159	1200 h	min. Mod	4000 h
4.)	20185	1200 h	min. Mod	4000 h
5.)	10891	800 h	red. Mod	1600 h
6.)	MLG	625 h	no Mod	on cond.
7.)	Fitting	1600 h	no Mod	on cond.
8.)	Mframe	2000 h	no Mod	on cond.

The present handling is still oriented to flight hour, OLMOS is presently providing statistical data and the Air Force is using the term "authorised Hours" to get better planning visibility. However the philosophy is changing to the term "on condition" and the present limitation may slip to higher values on the basis of measured load collectives.

The gained benefit is hard to calculate. Depot inspections to incorporate structural modifications are deleted or postponed. Not incorporated Modifications over a period of 10 years of operation.

Savings over the first 10 years (until 1993):	146 Mio DM (estimate)

The table does not provide any detailed figures due to classification restrictions. The overall figure should be considered as a rough estimate only.

4.5. Sensitivity Analysis

To find the best trade off between expenditures and benefit a sensitivity analysis is mandatory. A production aircraft is not providing measurement equipment to measure the forces affecting the structure of the aircraft during flight. Parameters easy to obtain are used to calculate affecting forces. The most important parameter to calculate forces is the accelerometer value in pitch direction. This parameter is provided by simple G meters collecting the various acceleration value during flight and record the different values. Because of the fact symmetric manoeuvring is more sufficient than asymmetrical manoeuvring, the acceleration values in the yaw and gear axis are neglected. The second important parameter is the actual weight of the aircraft, because the bending force in pitch direction is direct proportional the product "weight * acceleration". The weight of the aircraft is not available in the normal parameter set of aircraft parameters. It has to be calculated using the total take off cross weight including external weights (fuel tanks, weapons, EW pods) and subtract the cumulated weight loss (fuel consumed and dropped external stores). The Tornado is using a normal g-meter in the first 5 production batches, with OLMOS the weighted load collective is calculated and recorded.

Evaluating the data available, the following table shows the characteristically result:

Type of Monitoring	Main frame limitation
no monitoring	2000 h
G - meter	4000 h
OLMOS	8000 h

The result of this sensitivity analysis is an additional benefit factor of 2 using the more complicate method collecting weighted load collectives. If the baseline configuration without any monitoring is used as a reference, the benefit factor is 4. This situation is shown in more detail in the Annex.

5. ENGINE FATIGUE

Engine for military applications are designed for high thrust rates combined with low engine weights. Special material compositions and manufacture technologies are required to handle the high temperature environment. Similar to the airframe material deterioration is subject to intensive testing and ML (similar to FAA) approval. Flight safety critical modules require a special handling and high safety margins.

5.1. Basics

Modern Jet engines are operated in a high temperature environment at the edge of fatigue limits. From a standpoint of flight safety two types of material needs special treatment. Group A type materials are modules / parts that may cause catastrophically accidents (up to total aircraft losses) if the material bursts during operation. Group B type material are modules / parts that may cause drastically degradation of the engine performance if the material breaks or bursts during operation, however there is no fatal damage to the engine or the total aircraft expected.
Category A items are high energetic rotating parts or areas in the hot part of the engine (e.g. Combustion chamber). Fatigue fractions or thermal destruction has to be prevented by all means. If no load monitoring exists worst case considerations will lead to high safety margins and tremendous economical (logistic) losses. Therefore the knowledge of the actual load or stress profile is mandatory to utilise the material inherent life.

5.2. Engine Integrity Program

Critical elements for fatigue, like disks and shafts were subject of special fatigue testing during the development of the engine. A synthetic mission profile is used to get a good correlation to an average military mission. These destruction tests are using low cycle load changes to test the limits of the material solidity. For all group A parts the engine integrity program generates cycle limits that are subject to ML approval. Cycles can not be handled in the service, the only figure the usage can be measured is the "flight hour". An additional factor is invented and verified during the engine integrity program. This factor is called "Beta Factor" and is defined as the relation between "cycle" and "flight hour". The service release document, approved by the ML is showing "released cycles" and Beta factors. (Status 1981)

Component	released cycle	Beta
LPC Disk	16300	5,0
IPC Disk	14328	4,5
HPC Disk 1	9002	3,0
HPC Disk 2	14600	3,0
HPC Disk 3	5286	2,0
HPC Spacer 3	5306	1,5
HPC Spacer 4	5421	1,5
HPC Disk 6	4596	2,5
HPC Shaft	5048	2,5
HPT Disk	3015	1,54
IPT Disk	7791	2,8
LPT Disk	7500	2,5

The main result of the engine integrity testing was the establishing of TCI figures for all Group A parts of the engine with a high uncertainty referring to flight hours.

5.3. Expenditures for Engines

The installation of monitoring features related to the engine portion of the monitoring system is even more complicate than for the structure part. The following table will give an overview of the expenditure categories. They are principally identically to the expenditures related to the airframe.

1.)	A/C Modifications (cabling) to enable the embodiment of the maintenance recorder; new sensors including connecting cables
2.)	Embodiment of maintenance recorders testing, flight trials
3.)	Modification of DAU, HW update and SW development (Dornier, IABG, MTU and MBB)
4.)	Development of new Ground Equipment (HHT, RTU, OGS)
5.)	Procedure Changes and Adaptation in the central Logistic System
6.)	Procedure Changes Flight Line Organisation, Retraining

For the engine fatigue monitoring an estimated portion of the total development and retrofit costs applies.

1.) MR Wiring	Mod 480 B	cost
2.) MR Provisions	Mod 10825 A	cost
3.) MR Procurement	Mod 11052 A	cost
4.) Engine parameters for CR	Mod 01282 B	cost
5.) Oil pressure warning for CR	Mod 10863 A	cost
6.) IP spool speed probe	Mod 41088 B	cost
6.) DAU Update (% for engine)		cost
7.) MTU DAU SW (LCF)		cost
8.) AGE (OGS, HHT, RTU) (% for engine)		cost
9.) Log System Integration		cost
	Total expenditures	27,6 Mio DM

The table does not provide any detailed figures due to classification restrictions. The overall figure should be considered as a rough estimate only.

5.4. Benefit

The Benefit changing from flight hour oriented lived items to directly measured and calculated cycle counts is considerable. Knowing the real life consumption of the engine the originally authorised flight hours can be lengthened by a factor between 2 and 3 without the loss of flight safety. The following table is providing an overview of cost savings in the engine area. The following figures are based on an engine service life of 8000 flight hours and will just call out the spare part costs.

Component	gained life/ part change [h]	costs [kDM]
LPC Disk	2293	103
IPC Disk	2187	291
HPC Disk 1	3570	14
HPC Disk 2	3302	87
HPC Disk 3	2241	37
HPC Spacer 3	4391	11
HPC Spacer 4	4799	23
HPC Disk 6	2610	24
HPC Shaft	5068	156
HPT Disk	3057	60
IPT Disk	927	29
LPT Disk	4398	55
		890

This value reflects the savings of spare parts of one engine over the total lifetime. For the entire fleet (about 500 engines) the savings will be about 450 Mio DM. Assembling and disassembling labour is not called out. It may increase the overall savings by a factor of 2-3. The savings regarding a single engine over the entire lifetime may be in the neighbourhood of 2 Mio DM.

5.5. Sensitivity Analysis

The engine low cycle fatigue calculation is based on the gas path calculation of the engine. The temperatures and pressures are calculated at each stage. The parameters available used in this calculation are two revolutions (high pressure shaft and low pressure shaft), two temperatures (air intake and turbine blade) and two pressures (IAS and IALT). The third revolution (intermediate pressure shaft) is subject to this sensitivity analysis. The engine manufacturer insists on the best possible calculation and requested the installation of the IP spool speed probe. This probe is very unreliable (about 100 h MTBF) and the replacement an echelon 3/4 (industry) job. The intermediate spool speed can be measured or calculated, the calculation may have an error in the neighbourhood of 5 %. If the probe fails, the SW algorithm substitutes the measured parameter by a substitution calculation and reports a slightly higher usage to consider the possible error. The result of this analysis will be shown in the Annex.

6. ENGINE PERFORMANCE

Engine performance monitoring is quite complex and in production aircraft with limited parameters available not very accurate. However there is a good chance to monitor the performance of the engine using snapshot data taken at every mission at a reproducible situation. Trending these data for a longer time span gives the engine specialist the possibility of a reasonable performance diagnosis without engine ground runs and the usage of an engine test stand.

6.1. Basics

The Tornado engine is a three shaft axial jet engine that delivers close to 40 KN thrust. Due to the fact that the air crews are always in need of more power, the logistic side likes to run the engine with lower thrust levels to safe engine life, it was decided early in the program to adjust the engine control to a certain power level. That is called thrust rated operation. The mechanics have to guarantees the thrust ratio and adjust the control computer (DECU) accordingly. There are some effects that influence the thrust adjustment:

- increase of air leakage in the compressor stages
- pollution of temperature sensors
- failure of rpm sensors or other sensors

The air crew has to check the engine during the run up check using the HP RPM (N_H) and the Turbine bleed temperature (TBT) to decide upon a sufficient thrust level. This check has to be performed prior to Take Off and Afterburner engagement. This Run up check is used for the monitoring system, the parameters used are mainly N_H and N_L. The trend of N_H is indicating the amount of pollution on the temperature sensors and is an indicator for the military power level at the DECU (fuel rate). The N_L trend is indicating the thrust level.

The engine performance monitoring is using these trends to control deviations from the normal operation and to prevent ground engine runs. Corrections to the DECU is done using the method of "cold adjustment".

6.2. In-Service Experience

Trending of engine parameters needs reproducible snap shot trigger conditions. Data provided by the air crews can not be trended, the variation of the snapshot data is too large, the mathematical averaging impossible. With the introduction of the monitoring system the gained computer controlled snapshot data can be used for trending and troubleshooting. The ground runs of the engine can be reduced. The flight hour oriented maintenance concept can be changed to an efficient and reliable

on-condition concept. The evaluation of the engine trend is incorporated in the OGS. There is no information network available to distribute this information to other shops, mechanical specialists from other shops have to obtain the trending information at the OGS.

6.3. Expenditures for Echelon 1,2 Handling

The expenditures for engine performance are part of Echelon 1/2 expenditures listed under Chapter 7.3. The expenditure in the development phase include government work to assist the design. These costs are excluded in the figure 7.3. The retraining of the airforce personal and the change in the education system is excluded as well. There is another aspect on expenditures in the Echelon 1,2 area. The logistic benefit gained for the weapon system is mainly a benefit for the higher maintenance levels. There are less depot/ Industry inspections, or TCI changes on depot/ Industry level. Less manpower and less Mod Kits and spares are required. In order to obtain and deliver the information however, expenditures occur on the maintenance level in the operational unit. The mechanics have to keep the monitoring equipment operational, they have to obtain daily the information from the aircraft and they have to distribute the information into the logistic system. These expenditures are hard to extract fiscal values are not available. In the appendix principle considerations are shown to visualise this phenomenon.

6.4. Benefit

For the operational units fiscal benefits are hard to define. The following military attributes or values are used to characterise the benefit on operational level and substitute fiscal values:

1.) Availability of the weapon system

2.) Produced Flight Safety

3.) Planning Capability TCI

4.) Resource Optimisation

The monitoring of engine performance is giving a good example that the operational level is participating in the benefit. The availability is increasing, because all preventive engine ground runs to check the performance level of the engine are deleted. The daily work to collect trend data and do the evaluation is neglected. The produced Flight Safety can not be measured but the air crews have more confidence in the performance available and certainty in the system is increasing the safety as well. The available personal resources are better used. Unnecessary work is prevented.

7. STATIC OVERLOAD

Material deterioration occurs either cumulative or via static overload. Static overload situations may occur during flight, manoeuvring the aircraft outside the authorised flight limitations, or hard landings. The air crew is responsible to report static overload events, verified events lead to aircraft inspections.

7.1. Basics

Static overloads are tested during the fatigue test phase on dedicated airframe structures. As a result of these overload tests the flight limitations are established, the flight manual and the inspection manual are finalised. To observe overload situation cockpit instruments with memory functions are installed (e.g. g-meter). The Tornado is released up to different limits, depending on the various wing sweep angles and control angles (e.g. flap down, wing forward position). The air crew has to monitor certain parameters ($n_{Z,}$ speed, bank angle, crab angle) and correlate these parameters with the flight limitation authorised for the various control/wing positions. The service experience indicates a poor reporting discipline by the air crews, with the introduction of the monitoring system it was decided to incorporate static overloads into the monitoring system.

7.2. In-Service Experience

The experience with the event monitor (static overload events) is quite interesting and surprising. The air crews were going through a phase of uncertainty and frustration, because the system is much more accurate than the reporting discipline of the air crews. The maintenance personal were confronted with many events right at the edge where inspections could be prevented. From an air worthiness standpoint (ML) it became obvious that some of the limitations were too theoretical and require a more generous interpretation. The introduction of a dedicated inspection system was required to compensate the additional work inputted by the mechanics. Last not least, the de-confliction of limitations listed in the flight manual and the programmed trigger parameters in the monitoring system was required to prevent triggers "right at the edge".

7.3. Expenditures for Echelon 1,2 Handling

The installation of monitoring features related to the event portion of the monitoring system is different to the structure and engine part of the modifications. Basically the event monitor uses the available parameters from the baseline system, additional expenditures occur mainly in the new OLMOS DAU and the related ground components. The following table will give an overview of expenditures categories. For simplification purposes the category listed are comparable with the other expenditure tables.

1.) A/C Modifications (cabling) to enable the embodiment of the maintenance recorder; new sensors including connecting cables
2.) Embodiment of maintenance recorders testing, flight trials
3.) Modification of DAU, HW update and SW development (Dornier, IABG, MTU and MBB)
4.) Development of new Ground Equipment (HHT, RTU, OGS)
5.) Procedure Changes and Adaptation in the central Logistic System
6.) Procedure Changes Flight Line Organisation, Retraining

For the event monitoring and all other Echelon 1/2 activities an estimated portion of the total development and retrofit costs applies.

1.) MR Wiring	Mod 480 B	cost
2.) MR Provisions	Mod 10825 A	cost
3.) MR Procurement	Mod 11052 A	cost
4.) DAU Update (% for events)		cost
5.) DAU Event SW		cost
6.) AGE (OGS, HHT, RTU) (% for Echelon 1/2)0		cost
	Total expenditures 25,4 Mio DM	

The expenditures listed in the above table contains all expenditures related to the operation of an operational unit (wing). The separation into the various categories is not meaningful, because the data handling in the operational unit is not system oriented. The evaluation of parameters is following the same principle laws. Therefor the table contains the following sub tasks:

- Event Monitor (static overload events)
- Event Monitor (Diagnostic events)
- Engine Performance Monitoring

- Crash recorder/ Maintenance Evaluation

The table does not provide any detailed figures due to classification restrictions. The overall figure should be considered as a rough estimate only.

There is another viewpoint that can not be evaluated in fiscal units. The event monitor is more correct and precise than the air crew reports. The inspection work of the maintenance personal is increasing, as long as the trigger conditions are programmed right at the same value given in the flight manual, many event alarms are reported and many flights have to be evaluated, however in most of these cases inspections are not required.

7.4. Benefit

Using the same attributes or values
1.) Availability of the weapon system

2.) Produced Flight Safety

3.) Planning Capability TCI

4.) Resource Optimisation

to characterise the benefit on operational level the monitoring of static overloads gives the following benefit picture.

The availability of the total weapon system is up to now almost unchanged. False alarms and unnecessary evaluation may equal with inspection savings because of better information. The event monitor is subject of still ongoing improvements. Trigger conditions to be increased to get a certain clearance from the approved flight manual values and more specific inspection instructions by the industry are the main areas of improvement.

The additional gain of flight safety is compensating the a.m. disadvantages. This benefit is a great asset.

The resource optimisation is also a still ongoing improvement. Up to now the savings are minor.

8. DIAGNOSTICS

Diagnostics at complex military aircraft is a special discipline, general statements should be handled with reservations and every subsystem is confronted with special problems. Subsystems with a large amount of mechanical components need assistance from higher system levels to handle testability. Monitoring systems therefor can provide diagnostic assistance using the parameter correlation to identify abnormal conditions or failure events.

8.1. Main Diagnostic System

The main diagnostic system of the Tornado is called OCAMS (On-board Check out and Maintenance System). Tornado Subsystems or individual LRU´s (Line replaceable Units) are sending status signals to the central maintenance data panel (CMP). These status signals (discrete) are the result from the equipment built in test (BIT). A defect System or LRU will latch an indicator at the CMP. The maintenance personal is checking this CMP after every flight. The OCAMS is supplemented by the Main Computer Diagnostic System that provides additional information on the linked digital subsystems.

8.2. Supplementary Diagnostic System

The Tornado Monitoring System OLMOS has excess to additional aircraft raw parameters used for crash recorder and maintenance recorder. These parameters are available as long aircraft power is available and the signal producing systems are under power. The parameters are conditioned, accuracy, update rate and recording sequence are different. The diagnostic supplementary system is composed out of:

- programmable event system
- maintenance recorder system

The programmable event system allows the programming of predetermined events. If this event occurs the needed parameter are recorded and an indicator flag at the CMP is set. The evaluation will be done at the OGS. The maintenance recorder system allows the recording of complete missions. Special flight situations can be evaluated on ground, events can be located using special evaluation filters.

8.3. Expenditures Echelon 1,2 Handling

The expenditures for diagnosis are part of Echelon 1/2 expenditures listed under Chapter 7.3. The expenditure in the development phase include government work to assist the design. These costs are excluded in the shown table.

Using the monitoring system as a secondary diagnostic system higher qualification levels of the maintenance personal is required. Better education for dedicated maintenance personal has to be considered as additional expenditure.

8.4. Benefit

Using the same attributes or values

1.) Availability of the weapon system

2.) Produced flight safety

3.) Planning capability TCI

4.) Resources optimisation

the additional diagnostic capability is improving the availability of the system. The planning capability for TCI is improving. Specially in the present political situation flexibility is required, aircraft are operating out of their mainbase on Nato assignments or special training assignments. Having knowledge at the actual fatigue status or time left to the next depot inspection is important to the commanding staffs. The monitoring system is providing this visibility and saves additional funds and maintenance resources.

The entire trade off considerations on the maintenance situation in the operational units is shown in the appendix.

9. CONCLUSION

9.1. Benefit Operational Unit

The operational Unit needs a monitoring system to improve the availability of the weapon system. To get a better planning capability and a better resource management is as important as improving the flight safety situation.. The Tornado OLMOS is providing these features, future improvements however are still necessary and may be incorporated with the Flight Data Recorder Program. OLMOS as an integrated system allows easy and flexible handling and enable the wing to operate outside the main operating base. The benefit obtained for the operational unit is higher than the expenditure collecting data for the depot level and higher management. The logistic system is adapted to the automatic data collection and gives additional support to the operational unit, handling the configuration management and the overall data management.

9.2. Benefit Depot Level

The benefit for the higher maintenance levels can be accounted in fiscal units. There are not all expenditures and benefits available in fiscal units, the result still is quite impressive.

In the area of the structure a factor of 1:10 (expenditures:benefit) is observed. Over the entire service life of the structure a factor can probably be doubled. If the depreciation is taken in account a lengthening of the Tornado in-service life up to 8000 flight hours leads to a much higher figure.

In the area of the engine a factor of 1:40 (expenditures:benefit) is observed. The labour is estimated, no actual figures are available to amend the material costs.

The extraordinary savings on depot level justifies by itself the integrated monitoring system of the Tornado. It is assumed that the operating cost of the weapon system could not be afforded without the monitoring system OLMOS.

9.3. Improvements

With the introduction of the solid state data recorder an improvement of the monitoring system is expected. Data handling, event monitoring and ground evaluation will be improved. An updated version of the engine low cycle fatigue program will introduced simultaneously with the flight data recorder. A possible improvement is the better information distribution in the wing allowing the different shops a fast and safe data handling and evaluation. This improvement however will not be realised in the near future because of funding problems.

10. PORTABILITY AND EXPANSIBILITY

10.1 Portability of Objectives

There is no need to particularly emphasize that the objectives for OLMOS on Tornado also have a general validity. Modern weapon systems under development are mostly required to operate safely and reliable, as well as to be highly available, durable and, of course, effordable. Something the systems have got in common. They become increasingly complex and are operating at the edge of their loading capacities, always required to demonstrate superiority. Their attributes, like advanced manoeuvrability, computer aided autonomy, armament flexibility or tactical mobility and versatility, often make it difficult to achieve the above objectives economically, i.e. cost effective and within tactically acceptable down times.

Thus, the objective for OLMOS or any other equivalent system is to offer the most optimal and efficient assistance for the smooth and economic operation of the system itself and its interfaces with tactical command and logistic support systems. They therewith undertake a leading part in the assessment, preservation and restoration of the functioning ability and operational readiness of technical systems. This includes to facilitate and sustain all necessary organisational tasks and sequences, like status ascertaining, reporting and planning.

10.2 Portability of Principles

The Tornado On-board Life Monitoring System is collecting informations relevant to the aircraft's configuration and the actual development of its performance and remaining life. The data is continuously monitored and automatically processed on-board. Initial results are displayed to ground crews on the spot to indicate whether and where maintenance activities are required. Recorded data is being transfered easily and quickly into a ground system for further analysis and subsequent planning of maintenance tasks and supply demands. Although OLMOS does not fully cover the above, the functional principles behind it are applicable for other equivalent systems as well.

Also the operational principles of OLMOS are applicable in general. For instance, there is no need for additional personnel, interaction or dedicated power. That is to say, the monitoring system is an integral part of the system. As such it allows for computer aided monitoring and evaluation of trends, incidents and events. It collects and presents key informations required to exactly describe the system's status in short time and with the accuracy of modern data processing. Such operation improves flight safety, readiness and maintenance efficiency.

Of general purpose and importance is also to monitor the systems's configuration status. The status of individual hardware modifications and software releases will

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tell compatibilty and interoperability of the equipments. To record the serial numbers of equipments will enable their traceability during logistic management or accident investigations.

The portability of the monitoring principles of OLMOS require closer examination, to consider any differences between a fixed wing aircraft and a helicopter. Material deterioration, like fatigue, wear, corrosion or static overload, is a general failure cause. However, the actual occurrence of the failure can not easily be predicted. That is why the monitoring of vital mechanical parts in conjunction with stress imposing parameters is a means to concurrently increase operational readiness, flight safety and operational efficiency. This applies for monitoring the airframe as well as for monitoring the engine´s performance and fatigue. On a fixed wing aircraft the main operational stresses are caused by aerodynamic loads and hard landings, whilst on its helicopter counterpart vibrational loads are dominating. This difference does not alter the general validity of the monitoring principle, it might only be the reason for deviating implemtations.

The functional, the operational and the monitoring principles of the Tornado On-board Life Monitoring System have proven to be benificial for the operation of a weapon system. Other principles usually end up in the necessity to provide huge quantities of spare parts and maintenace activities, or to design a system with extremly high reliability, testability and maintainability performance characteristics. Both aims may be promissing, but they are unlikely to be cost effective and as contributing to operational readiness as could be.

10.3 Portability of Concept and Design

OLMOS was implemented by retrofit and has been founded on already existing components, which lead to a number of compromises. But even the belated introduction of a monitoring system payed off, as shown within this study. Due to ongoing computerisation some monitoring and control means are nowadays often already available. Processing power, storage capacities and miniaturisation technologies are developing rapidly. The retrofit concept is therefore a generally reasonsable approach.

Portability considerations of the monitoring algorithms require detailed technical expertise of the target system. Each aircraft has got its unique charakteristics to be monitored, but a number of failure causes follow the same principles, like deterioration of metallic parts. Hence, it can be assumed that the airframe fatigue monitoring algorithms used for Tornado will be portable onto a helicopter by amending the stress relevant parameters. Also the algorithms for engine monitoring are considered to be reusable after adaptation.

The software implementation of OLMOS was governed by the retrofit concept and therefore had to follow the design rules of the original equipments and development contracts. This environment will usually be different on another weapon system, having its own software design and support concept. Also, with later tools for software design and development or other microprocessors a new software implementation might look more preferable, unless the original OLMOS hardware shall be utilised.

The Data Aquisition Unit, the Crash/Maintenance Recorder and the Central Maintenance Panel on board, and the Hand-Held-Terminal, the Recorder Test Unit and the OLMOS Ground Station on ground form the key elements of OLMOS. Re-usability of the on-board hardware components will depent on the interfaces available and the signals to be monitored. Since algorithms and software is already deemed to be (at least partly) portable, and due to the fact that the on-board components are qualified to military standards, their portability is not generally out of question. But the efforts for adaptations should be carefully compared against alternative retrofit implemetations. The on-ground components are deemed to be more easily tranfered to other weapon systems, due to the simple serial link interfaces.

10.4 Expansion Potentials

To be effective the monitoring sytem should ideally be designed concurrently with the weapon system. All information required for complete configuration management, fault diagnosis, health and condition monitoring is to be generated, aquired, evaluated, recorded and transfered to other systems with minimum effort and instrumentation. However, a monitoring system should not only focus on the interior of the weapon system. It should be designed to fit into a flexible and powerful cooperation of the weapon system, the tactical command system and the logistic support system. It should utilise the opportunities modern computer and communication technologies are offering.

Via on-line communication logistic support management may know all the locations and times of demands for spares at any time. This enables economic planning and circulation of spares on the basis of condition-based, predictive maintenance. In addition, being continuously informed by tactical command as well as the weapon systems, logistic support management may immediately react upon shortcomings of spares and even strategic movement of the weapon systems. In return, tactical command may always know, which weapon systems are ready, for how long and what kind of weapon configuration. Tactical command may also be informed about the duration of repair and remedy actions as well as the capabilities of alternative systems intended to be tasked instead to successfully complete the tactical

mission. In front of such a scenario the weapon system itself is to provide essential information complete, correct and in due time.

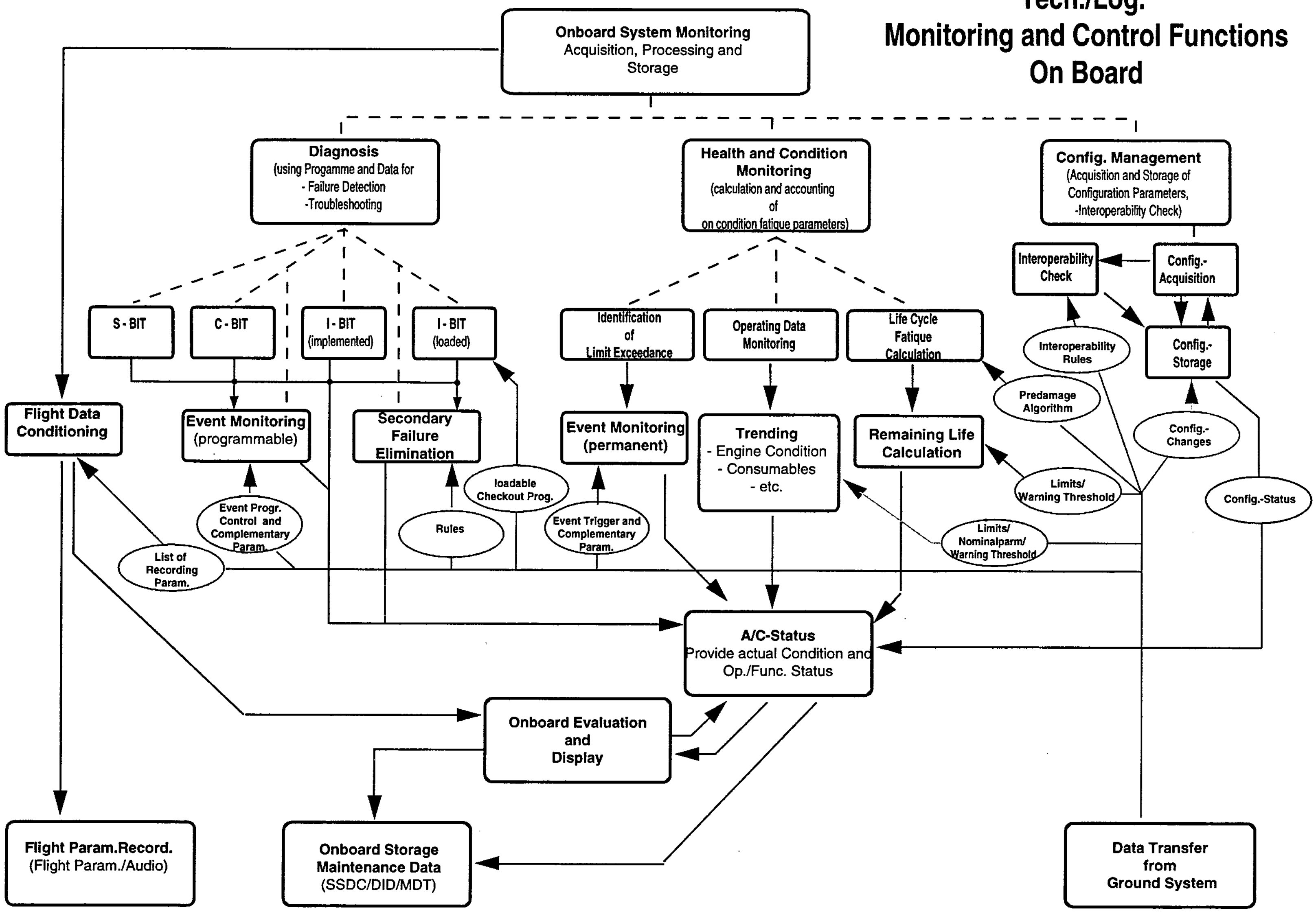
The figure on the following page details the technical-logistical on-board monitoring and control functions such a modern weapon system should be able to perform. The functions are integrated into the weapon system and only require mission specific and modification related information to be transfered from the ground station. All diagnosis, health and condition monitoring and configuration management functions are determined on board, including presentation of a complete picture of the aircraft´s status.

However, to achieve cost effectiveness and optimum operational readiness, it is important to find realistic approaches. When defining the requirements for a monitoring system, the distribution of tasks requires careful consideration. From the nature and the criticality of each failure the appropriate monitoring means is to be derived. Some failures will have to be subjected to safety related turn-off mechanisms, others can be handled by control loops. A number of failures can be avoided by condition monitoring and pedictive maintenance. There will also be failures that should better be oberserved manually to be cost effective, and finally failures which will cause such insignificant cost that any monitoring is not worth the effort.

Another aspect to be considered is the trend to integrate off-the-shelf equipment when purchasing a new weapon system. This approach on its own already indicates that there are small budgets for development and adaptations. Thus, it will be challenging to achieve all of the above performances. It will require fairly intensive engineering management and trade-offs to concentrate efforts on the monitoring of the right paramenters with the appropriate means. Modern engineering techniques are coming towards this task, by providing more and more information electronically, which enables fast and easy evaluation and re-usability throughout the procurement and operational phases.

On OLMOS, some of the above tasks have been implemented into on-board and on-ground systems. This is the basis for further developments. The requirements for the Ground Support Systems for the EF2000 aircraft are currently being analysed and those for the EuroCopter Tiger Dornier is discussing with both, the Customer and the helicopter´s manufacturers. The views developed during these exercises lead to the above vision of an effective and superior technical logistical system. Being convinced of the increasing economical and tactical benefits, Dornier continues to find solutions for the information and communication demands of modern weapon systems.

Tech./Log. Monitoring and Control Functions On Board



ANNEXES

Annex 1 : Benefit-Value-Analysis

Figure 1

Fig 1 gives an overview of all Alternatives discussed during the decission phase of OLMOS. It shows the Tornado Baseline right after the development phase as the first alternative and is ending up with the OLMOS maturing in connection with the flight data recorder program.

The various alternatives are verified against the objectives the monitoring system should reach. Looking at the various objectives "points" are assigned to every alternatives to indicate the degree of objective fulfillment. The criteras the "points" are assigned are based on the experience from the working group OLMOS and in service trial experience. The assigned points are scaled from 0 to 10 to allow a better comparison.

Extension Inspection Intervall

With the base line Tornado some mission profil verifications are possible using the crash recorder. The synthetic profil used in the MAFT was identified as too hard, evaluation the first in service flights. The gained results were not sufficient enough to get a relieve from ML.
With the G-meter a better indication was possible. The load profiles are indicating more detail facts. A first extension of inspection intervall was possible.
The 100% maintenance recorder solution is providing the total visibility and the MAFT and assotiated load programs could be verified. The maximum of 10 points are reached.
With the integrated OLMOS it was possible to use the "weighted load collective" as a reference system to the MAFT, the same transperency as the 100 % MR soltion was reached. The maximum of 10 points was assigned.

Strain oriented Part Change for Structure

A similar fulfillment of criterias can be observed. The base line program did not allow any relieve in the tough TCI plan. The modification required are based on the MAFT results. No changes were possible. The crash recorder did not provide enough data to allow any changes to the

procedure.
The introduction of the G-meter did allow a extension of in service life time of the structure. The first modification slippages were indicated.
The 100% maintenance recorder solution is providing the total visibility and the MAFT and assotiated load programs could be verified. The maximum of 10 points are reached.
The integrated OLMOS is also showing to total picture of fatigue. The maximum points of 10 are assigned.

Strain oriented Part change for Engine

With the base line Tornado some mission profil verifications are possible using the crash recorder. The synthetic profil used in the ensip integrity program was identified as too hard. The Beta factors could be adjusted, over a long evaluation period some gain in TCI life is possible. This situation is not changed by the introduction of the G-meter, therefor 2 points were assigned for the first 2 alternatives.
The introduction of a fleetleader program MR (about 5 to 10 %) is providing a better visibility of engine fatigue, this is indicated by the assignment of 4 points.
The 100% maintenance recorder solution is providing the total visibility and the MAFT and assotiated load programs could be verified. The maximum of 10 points are reached.
The introduction of the OLMOS gives also total visibility to engine fatigue, the maximum of 10 points are assigned.

Recording Static Overload Structure / Engine

The base line, G-meter and Fleet Leader Progam MR does provide a limited feature. Using the CR for Overload evaluation (based on crew reports) a limited verification is possible. With the Fleet Leader Program some additional evaluation routines are possible, however no practicable procedure for in service use can be provided. Because of this limited capability 2 points will be assigned.
The 100% MR program allows the principle usage of this feature, the high effort required to obtain the data after each flight allows just the assignment of 6 points.
The integrated OLMOS provides the features, however there is still a

limitation to storage and the amount of recorded parameters, therfore only 7 points are assigned.

The maturing expected with the FDR program will add additional features, more recording space and a more flexible datahandling.

Recording Static Overload Controls / External Loads

The base line, G-meter and Fleet Leader Progam MR does not provide this feature. With the Fleet Leader Program already some additional evaluation routines are possible, however no practicable procedure for in service use can be provided. No points are assigned to these alternatives.

The 100% MR program allows the principle usage of this feature. There are good routines available monitoring the controls and external stores, however the high effort required to obtain the data after each flight allows just the assignment of 7 points.

The integrated OLMOS provides the features, however there is still a limitation to storage and the amount of recorded parameters, therfore only 8 points are assigned.

The maturing expected with the FDR program will add additional features, more recording space and a more flexible datahandling.

Parameter Recording / Aircraft Parameter Evaluation

With the base line program parameter recordind on the CR is realised. The data content is quite sufficient, the sampling rate adequate. The CR does not provide data for the entire mission, there is only a 60 minutes recording on endless tape possible. The data dump is inconvenient, a 1:1 data retrieval (1 hour of retrieval time) is inconvenient for the user and depresses the availability situation of the aircraft.Therefor only 4 points will be assigned.

The additional MR in the fleet leader program improves the situation data evaluation will be easier for the MR aircraft and additional technical verification programs can be performed. 6 points will be assigned to that alternative.

A 100% MR alternative gives the best parametric support, even more than the OLMOS. A complete 100% solution will be reached again with the FDR program, the retrieval is fast and accurate and will not limit the operational

use of the weapon system. 10 points are assigned to the MR alternative and the FDR.

Flexible and Efficient Flight Operation

Data evaluation and monitoring the system is in all cases a burden for the operational handling of the weapon system. Air crews require the total flexibility to get best utilisation from the system. Maintenance activities should be invisible and not limit a mission. Therefor it is very difficult to compare the various alternatives regarding flexibility and efficiency. The result from in service trials indicate that flexibility and efficiency is decreasing with more monitoring activities based on the principle: "on board recording and on ground processing". The increase of monitoring activities with MR is decreasing the fulfillmentrate of the objective criterias. The assigned points are decreasing from 3 to 0 with the full MR solution. The OLMOS alternative is obtaining 7 points, that means inproving the system with the FDR program is possible and necessary.

Diagnostic and Maintenance

Diagnostic and maintenance is starting to get involved with the Fleet Leader program MR. The earlier alternatives have no points assigned. The 100% MR and OLMOS alternatives are showing some reasonable diagnostic and maintenance improvements (6 and 7 points). The FDR is providing a considerably increase of these features and will get 10 points.

Userfriendly Operation

Userfriendly operation is increasing with the amount of automisation on board and the evaluation tools available on ground. The classic on board recording devices need a lot of personal engagement. The base line program does not have a routine maintenance interface, therfor 0 points are assigned.
G- meter requires a manual action reading the meter and fill the data manually in a formula. The formulas are sent to industry. This procedure is very complicate for the user, there are many possibilities of mixing up the recorded data or to generate editing errors. Just 2 points are assigned.
The automation process provided by OLMOS is very userfriendly and the

evaluation features provided have a high degree of user acceptance. 8 points are assigned.

The FDR program has still room for improvements an increase in this area is expected.

Safe and Reliable Data Handling

The data used in the monitoring area have to be handled like documents. Flight safety is involved and the approval of ML required. This criteria is giving an indication how reliable the data collection and transfer is organised. The base line program do not provide related data, therefore no points are assigned.

The G-meter alternatives require accurate data handling. The principle is still simple the data handling is functioning sufficiently, because not many data have to be traced. 6 points.

The 100% MR alternative requires a lot of administrative data handling to trace every individual flight. Therefore only 4 Points are assigned.

The OLMOS is providing many configuration control features data handling is safe and reliable, not many improvements are expected with the FDR program. (9 / 10 points).

Figure 2

Fig 2 gives an overview of the Single Benefit using the "point system" of Fig. 1 with an overlay of weight factors. The weight factors used reflect user aspects and logistic requirements. The criterias are categorised in three sections:

Fatigue monitoring	40%
Extension Inspection Intervall	10%
Strain oriented Part Change Structure	10%
Strain Oriented Part Change Engine	20%
Parameter monitoring	20%
Recording Static Overload Structure	7%
Recording Static Overload Controls/ Loads	7%
Parametric Recording A/C Parameters	6%
Operation and Handling	40%
Flexible and efficient Flight Operation	15%
Diagnostic and Maintenance	7%

Userfriendly Operation	8%
Safe and reliable Datahandling	10%

The resulting figures are called "weighted criterias". The weight factors are the result from OLMOS in service trials and working group discussions.

Figure 3

In Fig 3 the weighted criterias are summerised. The method used in the Value Synthesis is the addition method, a method where "0" criterias are not authomatically elimitate the alternative. result This method gives better transperency , if the Value Synthesis is gained by the multiplication method all "0" criterias will generate "k.o." criterias. By doing so the 100% MR solution will be elliminated.

Figure 1: Proceedings

Proceedings

	Extension Inspection Intervall	Strain oriented Part Change Structure	Strain oriented Part Change Engine	Recording Static Overload Structure / Engine	Recording Static Overload Controls / External Loads	Parametric Recording Aircraft Parameters Evaluation	Flexible and Efficient Flight Operation	Diagnostic and Maintenance	Userfriendly Operation	Safe and Reliable Data Handling
Tornado with Crash Recorder (Base Line)	2	0	2	2	0	4	3	0	0	0
Base Line + G-Meter	5	4	2	2	0	4	2	0	2	6
Base Line + G-Meter + Fleet Leader MR	5	5	4	2	0	6	1	2	1	6
Base Line + 100% MR	10	10	10	6	6	9	0	6	1	4
Base Line + OLMOS + Fleet Leader MR	10	10	10	7	8	8	7	7	8	9
OLMOS Maturing + Flight Data Recorder	10	10	10	9	9	10	10	10	10	10

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Figure 2: Single Benefit

Single Benefit

	Extension Inspection Interval	Strain Oriented Part Change Structure	Strain Oriented Part Change Engine	Recording Static Overload Structure / Engine	Recording Static Overload Controls / External Loads	Parametric Recording Aircraft Parameters Evaluation	Flexible and Efficient Flight Operation	Diagnostic and Maintenance	Userfriendly Operation	Safe and Reliable Data Handling
Weight Factor	**10**	**10**	**20**	**7**	**7**	**6**	**15**	**7**	**8**	**10**
Tornado with Crash Recorder (Base Line)	20	0	40	14	0	24	45	0	0	0
Base Line + G-Meter	50	40	40	14	0	24	30	0	16	60
Base Line + G-Meter + Fleet Leader MR	50	50	80	14	0	36	15	14	8	60
Base Line + 100% MR	100	100	200	42	42	54	0	42	8	40
Base Line + OLMOS + Fleet Leader MR	100	100	200	49	56	48	105	49	64	90
OLMOS Maturing + Flight Data Recorder	100	100	200	63	63	60	150	70	80	100

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Figure 3: Value Synthesis

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Value Synthesis

Total Benefit Value of Alternatives

Tornado with Crash Recorder (Base Line)	143
Base Line + G-Meter	274
Base Line + G-Meter + Fleet Leader MR	327
Base Line + 100% MR	628
Base Line + OLMOS + Fleet Leader MR	861
OLMOS Maturing + Flight Data Recorder	986

Annex 2: Structure Fatigue

Figure 4

Fig 4 gives an overview of the collected stress value of individual aircraft. The diagram shows two clouds of aircraft (Jever and Memmingen) and there individual stress situation. The Jever wing is a training wing where young pilots are trained in the tactical combat program, Memmingen is a standard IDS wing. The stress values shows a statistical average of the Jever aircraft ending up at 6900 flight hours, and the Memmingen fleet ending up at 9100 flight hours. The diagram indicates the realistic overall stress situation allowing about 8000 h of operation and the estimated 2000 h of the MAFT prognosis.

Figure 5

Fig. 5 is reflecting the Sensitivity Analysis. The Memmingen fleet is compared with another operational Unit (Jagel) using early production aircraft. These aircraft were equipped originally with the G-meter and the backward interpolation is ending in an average useage curve of 4000 flight hour. The data are not available in detail but they are based on industry records from IABG. The Jagel aircraft were retrofitted from G-meter to OLMOS, however the values collected from the G-meter were never corrected. The curve may end up in a long run also in the neighbourhood of 8000 flight hours.

Figure 4: Collected Stress Values

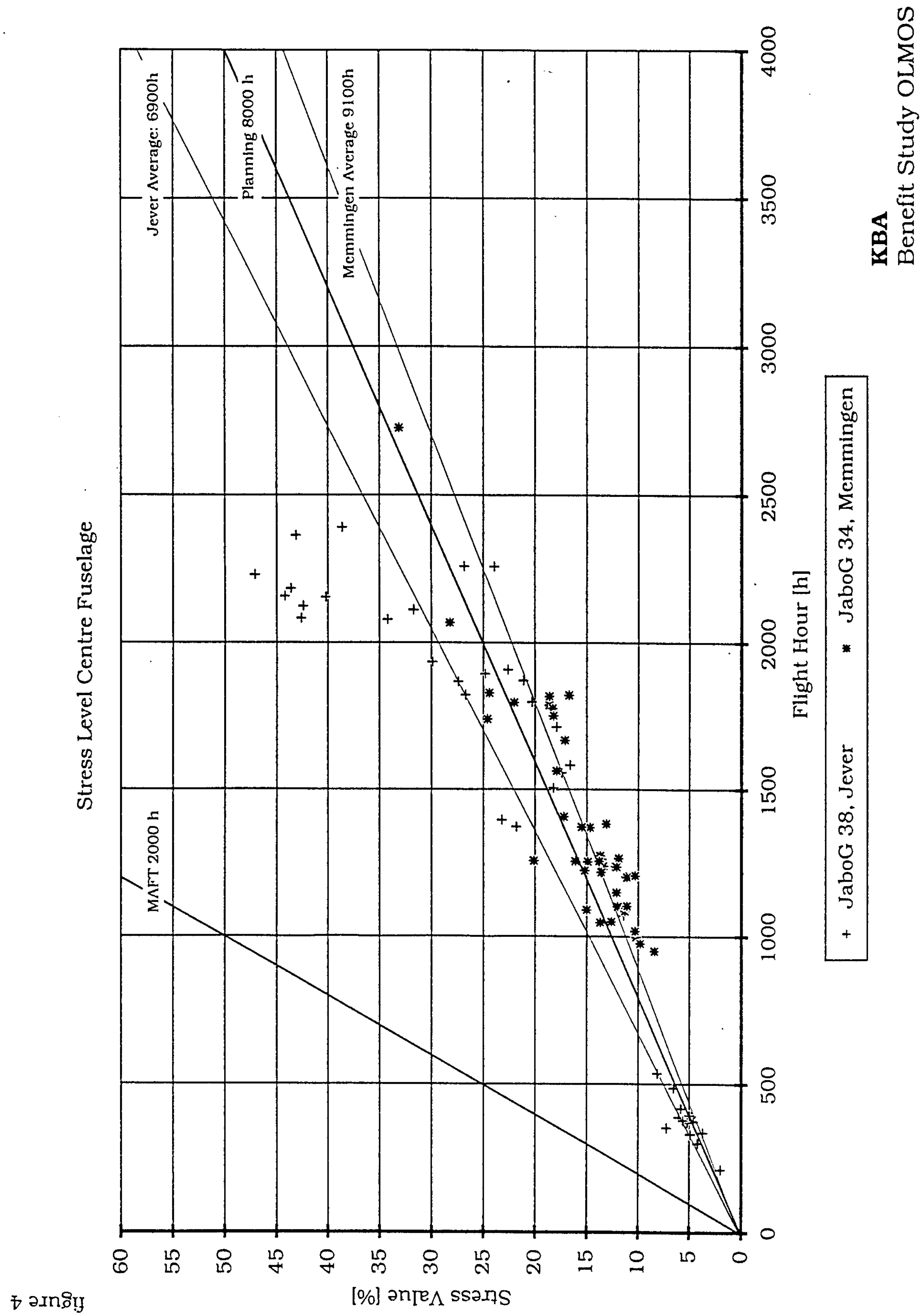

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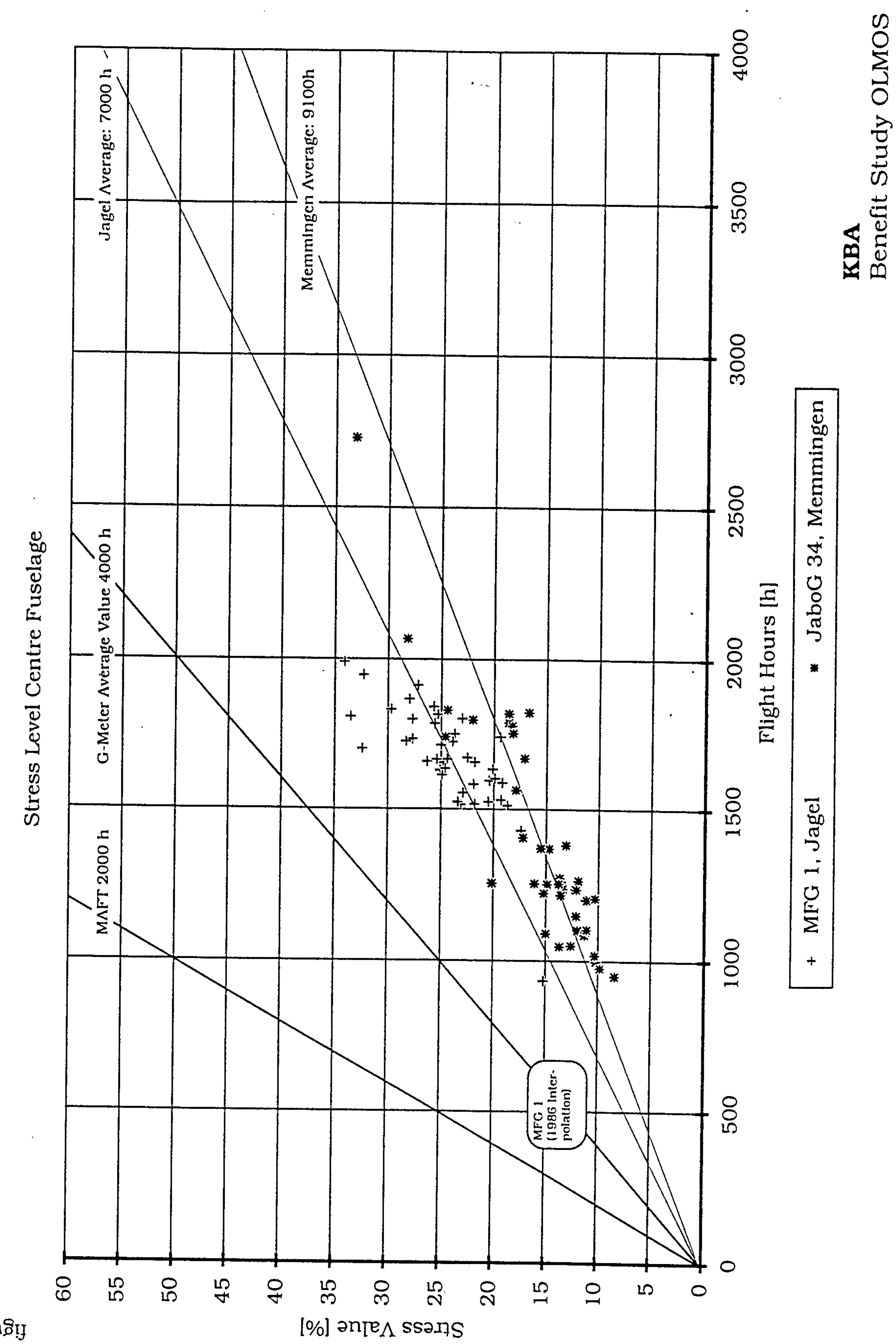
Figure 5: Sensitivity Analysis



Annex 3: Engine Fatigue

Figure 6

Fig 6 gives an overview of the stress situation of the Group A parts of the engine. The table shows the authorised cycles and "beta-factors" at the begin of the Tornado program. The Beta factors were adjusted in 1985. This adjustment is based on in-service trials, however the result was on the "very safe side" and the released flighthours were on a very low level. The introduction of OLMOS was showing a much better picture (Beta 1991). In 1991 20% - 30% of the Tornado fleet were equipped with OLMOS and based on these aircraft accounts the Beta values were adjusted. Therefore this collumn is showing the statistical average of the entire fleet. The 1994 figures are actual measured cycles, converted to flight hours for better understanding. The benefit study is using this figures for the fiscal benefit, comparing the values with the data from 1981. Using the values from 1985 the gained benefit would be much higher.

Figure 7

Fig 7 gives an graphical overview of this situation. There is one curve (Low pressure Turbine) which shows unlogical values in 1985. This value could not be varified, however the overall trend can clearly be shown.

Figure 8

This figure is based on the results of the in-service trials in Jever airbase. The table shown shows the variety of Tornado missions. Air crew training missions (listed under "Training") and IDS missions (listed under IDS) the average life consumption is in line with the authorised Beta values. There is one mission identified as a very life consuming mission listed under "High speed Jojo" (H.Sp.Jo). This mission was a performance demonstration flight and shows an extreme high LCF consumption. This mission is selected to proof the need of a fleet wide monitoring system. These extreme situations can not be caught by statistical methods, using statistic the logistic loss and the flight safety risk would be too high.

Figure 9

This figure is reflecting the situation of the N_l RPM counter. This sensor was added to the engine in combination with the Monitoring System. The counter was identified as a low reliable component, after 100 hours of operation (average MTBF) the sensor fails. To repair or substitute the sensor the engine has to be turned in to depot level repair. The repair is very expensive because the engine has to be disassembled completely to reach the inner shaft. A substitution SW increment was

developed to calculate the LCF when the sensor fails (substitution calculation). The SW is using the measured N_l if available, and uses the substitution calculation if the sensor fails. The diagram is reflecting the situation getting more accuracy with the sensor signal available and less accuracy when the sensor fails. Repairing the sensor means a lot of additional efforts to be spent, with little increase of benefit.

Figure 6: Stress Overview Group A Parts

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Stress Overview Group A-Parts

	Cycles	ß (1981)	ß (1985)	ß (1991)	1981	1985	1991	1994
LPC Disk	16300	5,00	8,00	4,66	3260	2038	3498	4331
IPC Disk	14328	4,50	15,00	9,28	3184	955	1544	3142
HPC Disk 1	9002	3,00	3,00	1,66	3001	3001	5423	6571
HPC Disk 2	14600	3,00	9,40	4,72	4867	1553	3093	4855
HPC Disk 3	5286	2,00	3,90	1,97	2643	1355	2683	3596
HPC Spacer 3	5306	1,50	2,20	1,22	3537	2412	4349	6803
HPC Spacer 4	5421	1,50	2,30	1,28	3614	2357	4235	7156
HPC Disk 6	4596	2,50	1,50	1,12	1838	3064	4104	5674
HPC Drum	5048	2,50	2,70	1,03	2019	1870	4901	6938
HPT Disk	3015	1,54	1,50	1,80	1958	2010	1675	5067
IPT Disk	7791	2,80	4,20	4,20	2783	1855	1855	2782
LPT Drum	7500	2,50	1,00	1,77	3000	7500	4237	7398

1. Authorized cycles iaw GAF T. O. 1F-PA200-6, Issue 13.9.91
2. ß-Factors: historical development since 1981
3. Columne "1994": measured cycle accounts by OLMOS MK 101 +20%

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figure 7

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Stress Overview Group A-Parts

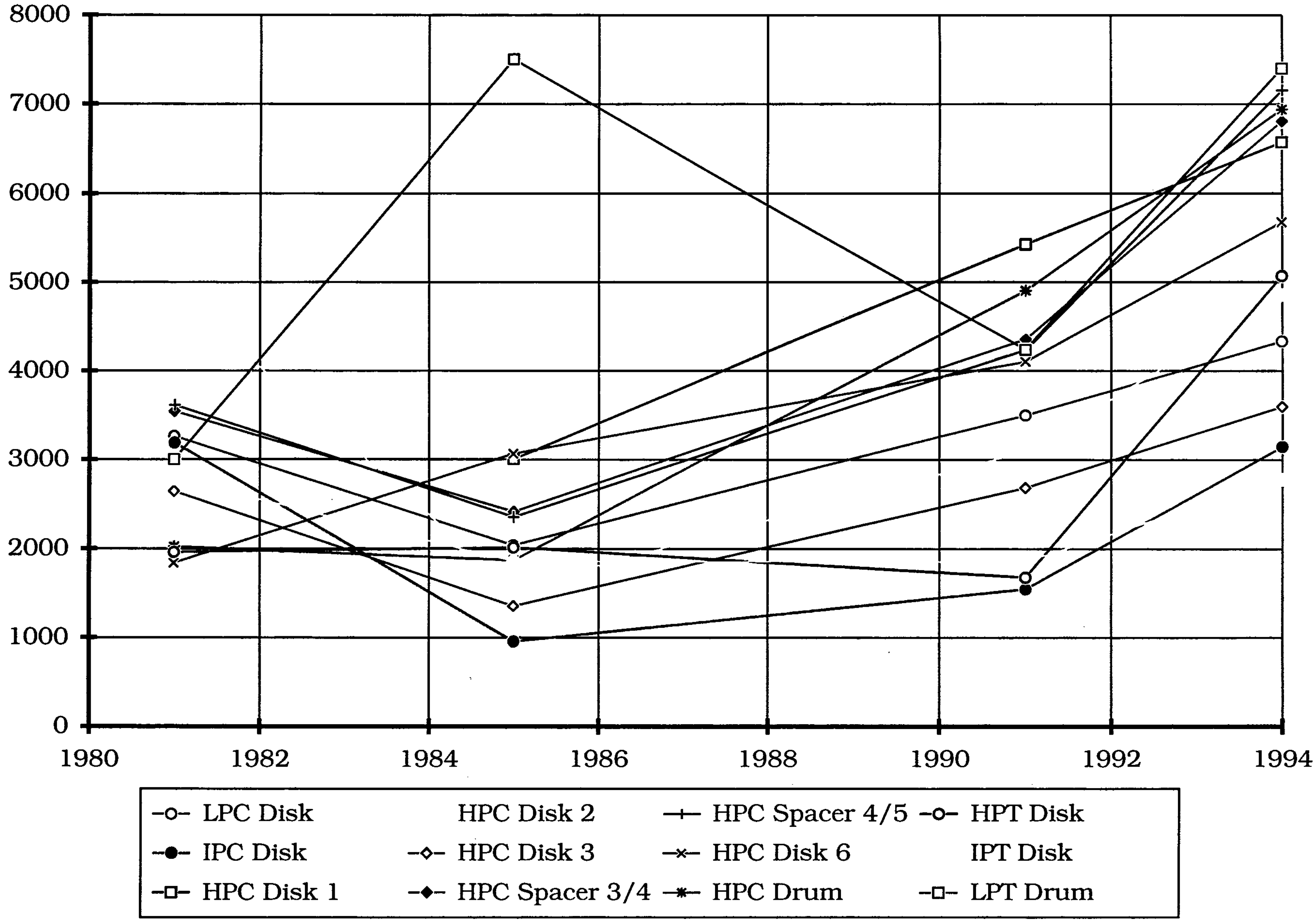
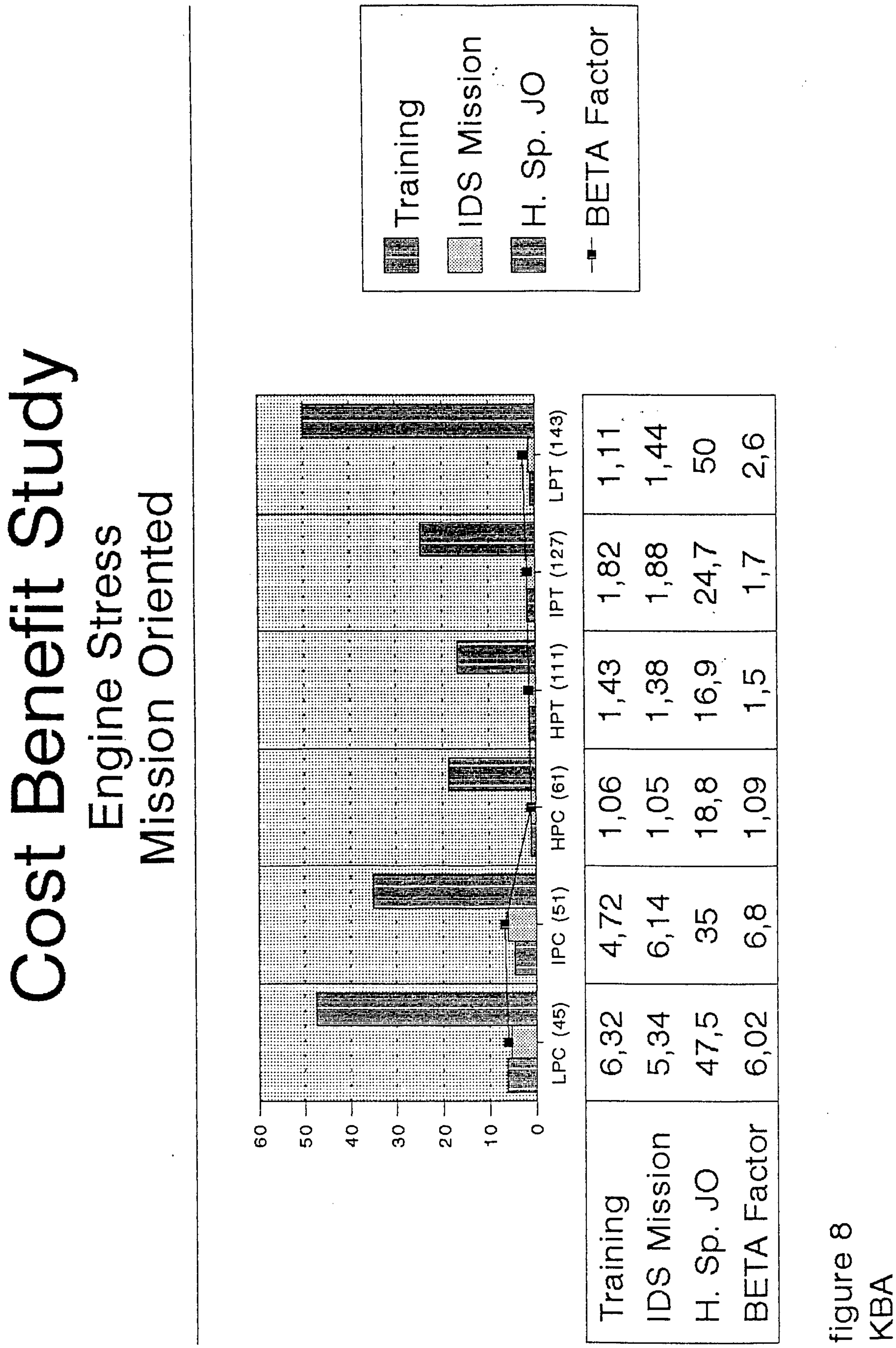
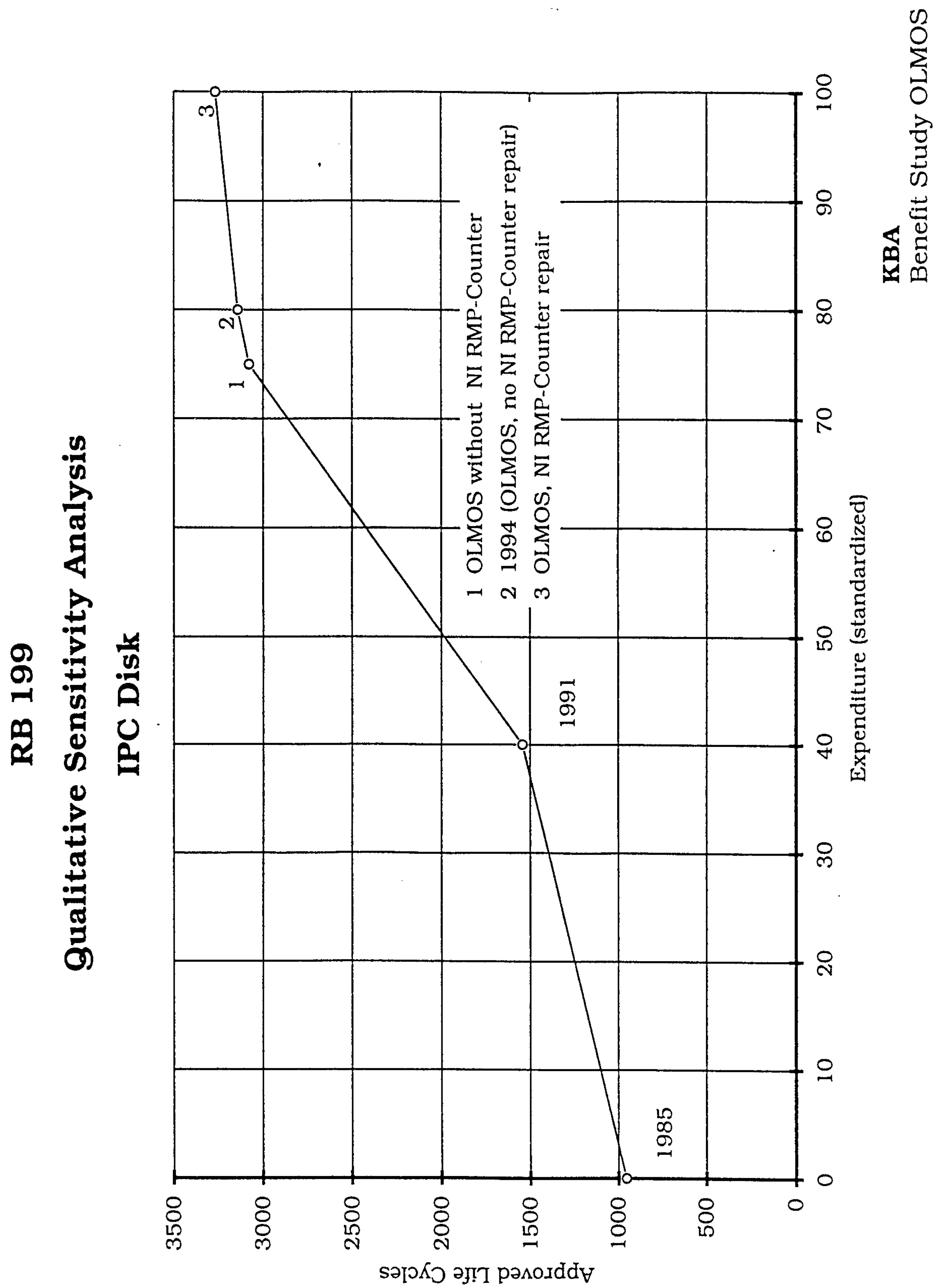


Figure 8: Engine Stress Mission Oriented



	LPC (45)	IPC (51)	HPC (61)	HPT (111)	IPT (127)	LPT (143)
Training	6,32	4,72	1,06	1,43	1,82	1,11
IDS Mission	5,34	6,14	1,05	1,38	1,88	1,44
H. Sp. JO	47,5	35	18,8	16,9	24,7	50
BETA Factor	6,02	6,8	1,09	1,5	1,7	2,6

Figure 9: Qualitative Sensitivity Analysis



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Annex 4: Echelon 1,2 Benefit

Figure 10

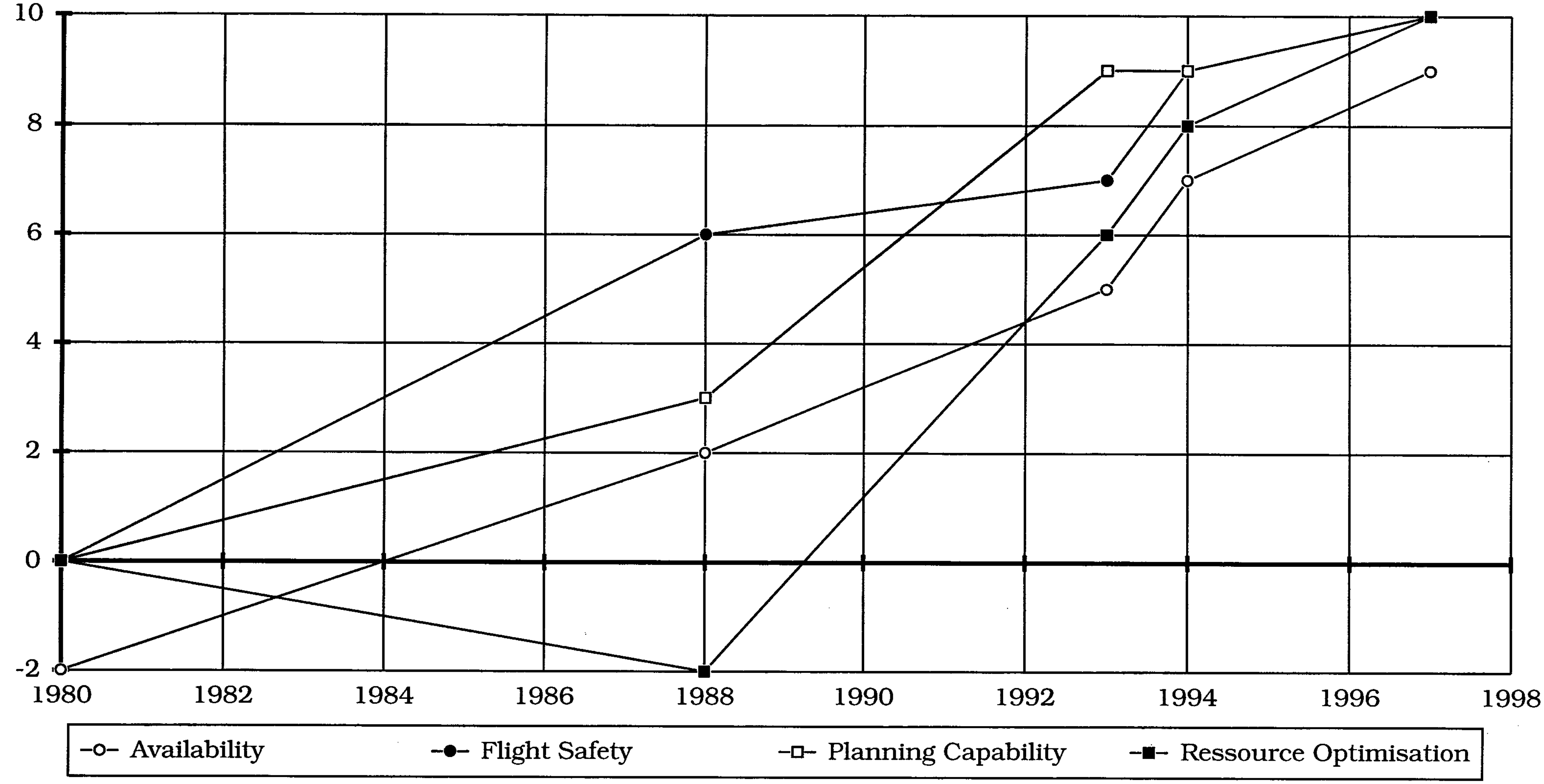
Figure 10 shows the development of Echelon 1,2 benefit in the areas of availability, flight safety, planning capability and resource optimisation. The historical development indicates that the System needed additional resources in the beginning and a relieve became obvious with the introduction of an improved event monitor. The FDR introduction may provide an additional improvement. The diagram is a principle diagram because no fiscal benefit figures can be provided. The scale is reflecting a maximum standardised benefit figure of 10.

Figure 11

This figure shows a combination of Echelon 1,2 benefit (wing) and Echelon 1,2 expenditure that is required to provide the data for higher level (echelon 3,4, depot). The historical development shows the increase of "effective benefit" over the years. It is obvious that the user acceptance (echelon 1,2) is increasing with the increase of the wing level maintenance benefit. A system that does not provide any benefit for echelon 1,2 will be burden for the operational unit.

figure 1(

Standardized Benefit MES 1/2



1980:Base Line + G-Meter

1988: Basic Functions OLMOS

1994: Maturing Event Monitor

1997: Estimation after FDR Embodiment

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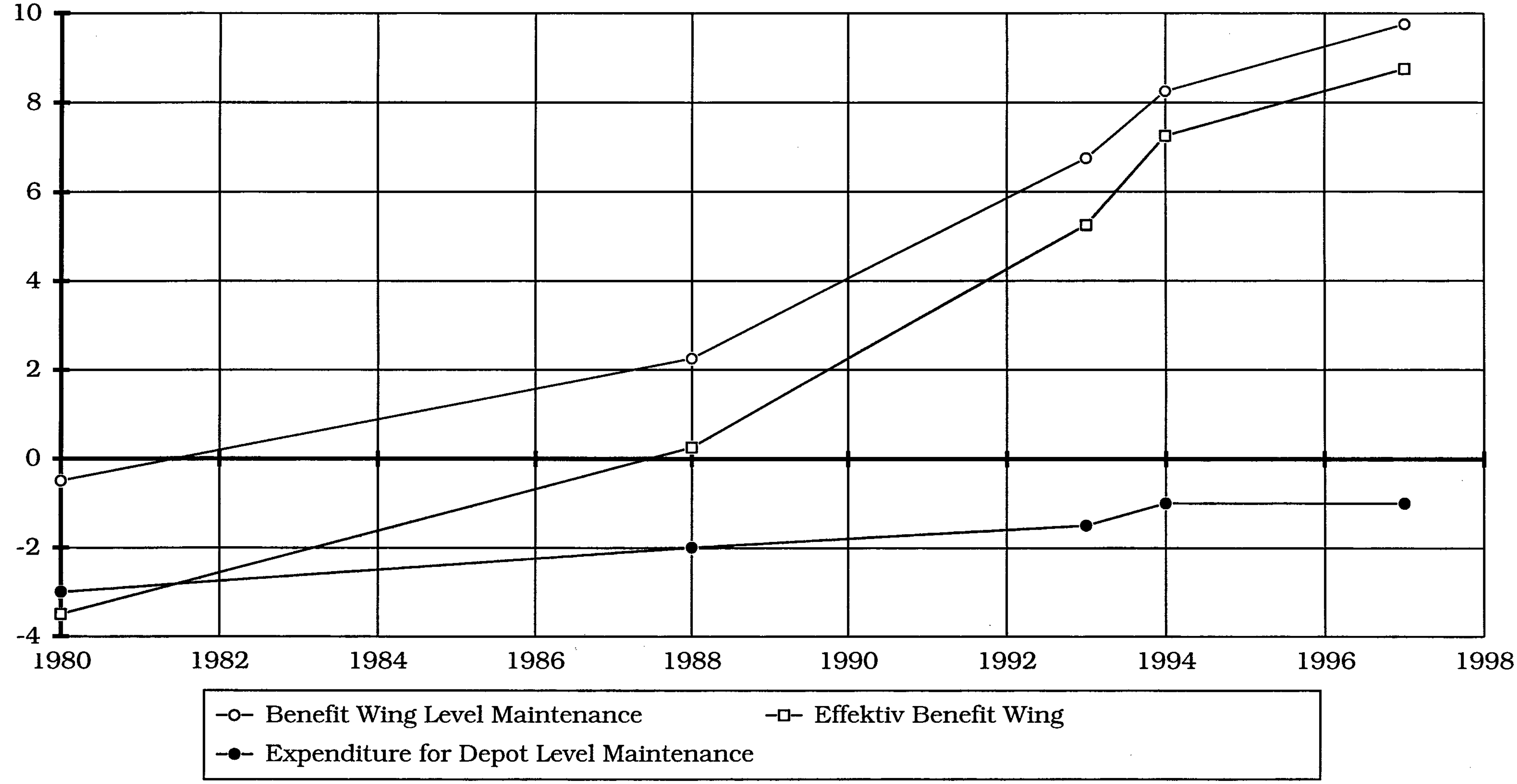
figure 1:

EffektiveBenefit Operational Unit (Wing)



1980:Base Line + G-Meter

1988: Basic Functions OLMOS

1994: Maturing Event Monitor

1997: Estimation after FDR Embodiment

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Annex 5: List of Abbreviations

AC	aircraft
AGE	aerospace ground equipment
BIT	built in test
CMP	central maintenance panel
CPU	central processing unit
CR	crash recorder
DASA	Daimler Benz Aerospace (German firm)
DAU	data acquisition unit
DECU	digital engine control unit
DI	depot inspection
EW	electronic warfare
FDR	flight data recorder
G meter	accelerometer in pitch direction
HHT	hand hold terminal
HP	high pressure
HPC	high pressure compressor
HPT	high pressure turbine
HW	hardware
I/B	inboard
IABG	Industrie Anlagen Betriebsgesellschaft (German firm)
IALT	indicated altitude

IAS	indicated air speed
IP	intermediate pressure
IPC	intermediate pressure compressor
IPT	intermediate pressure turbine
KN	kilo newton
LCF	low cycle fatigue
LPC	low pressure compressor
MAFT	major aircraft fatigue test
ML	Musterstelle Luftfahrzeuge (German FAA)
MLG	main landing gear
MR	maintenance recorder
MTBF	mean time between failure
MTU	Maschinen Turbo Union (German firm)
N_H	RPM high pressure
N_I	RPM intermediate pressure
N_L	RPM low pressure
OCAMS	on board check out and maintenance system
OGS	OLMOS ground station
OLMOS	on board life monitoring system
RPM	revolutions per minute
RTU	recorder test unit
SW	software
TBT	turbine blade temperature
TCI	time changed item

Annex 6: References

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